Egypt. Public works dept.

REPORT

ON

PERENNIAL IRRIGATION AND FLOOD PROTECTION

FOR EGYPT

BY W. WILLCOCKS, M. I. C. E.

DIRECTOR GENERAL OF RESERVOIRS,

WITH

A NOTE

BY W. E. GARSTIN,

UNDER SECRETARY OF STATE, PUBLIC WORKS DEPARTMENT, EGYPT.

CAIRO:

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To

His Excellency RIAZ PACHA,

President of the Council of Ministers.

Excellency,

I have the honour to submit to you the following papers in connection with the question of Reservoirs.

(1) My note upon Mr. Willcocks' Report.

(2) Mr. Willcocks' Report on " Perennial irrigation and flood protection for Egypt ".

(3) Appendices to the Report. Appendices XI and XII are notes on the utilisation of Reservoir water by Major Brown and Mr. Foster, the inspectors General of Irrigation for Upper and Lower Egypt respectively. Appendix XIII is a note by Dr. G. Schweinfurth upon the question of salt in the Wadi Rayyan.

(4) The Plans and Designs accompanying the Report.

I have the honour to be,

Excellency,

Your obedient servant,

W. E. Garstin,

Under Secretary of State,

Public Works Department.

Dated, Cairo, 27th December, 1893.

NOTE

ON

"PERENNIAL IRRIGATION AND FLOOD PROTECTION FOR EGYPT"

BY

W. E. GARSTIN,

UNDER SECRETARY OF STATE, PUBLIC WORKS DEPARTMENT, EGYPT.

L.E. 1 = 100 piastres = Lst. 1.. 0ˢ.. 6ᵈ.

1	feddan (Egyptian acre)...	=	4200	square metres.
1	acre (English)	=	4047	» »

1	metre	=	3.28	feet.
1	square metre...........	=	10.76	square feet.
1	cubic metre............	=	35.32	cubic feet.
1	kilogramme	=	2.205	pounds.
1,000,000	cubic metres per day....	=	400	cubic feet per second.

Note on Mr. Willcocks' project for "Perennial irrigation and flood protection", by W. E. Garstin, Under Secretary of State, Public Works Department, Egypt.

The Report.

On the submission of Mr. Willcocks' preliminary Report on Reservoirs in 1891, my predecessor, Sir Colin Scott Moncrieff, decided that detailed information should be collected about every reservoir site in Egypt. The present report embodies this information, and I am now in a position to make definite proposals to the Government. A glance at the project will show the extent and range of the questions which have been considered.

Appendices and Plans.

The Report is accompanied by ten appendices containing a mass of information and calculation, and 37 sheets of plans and designs. Among the latter is a complete survey of the Nile from Wadi Halfa to Cairo.

With the help of Professors Sickenberger and Hudson Beare, the geology of the region has been studied, and the strength of the different building stones tested.

The entire project has taken 4 years to prepare, a period of time which cannot be considered excessive if we contemplate the importance of the subject and the range of the enquiries.

The Staff.

On page 17 of his Report, Mr. Willcocks gives the names of the members of his staff. I fully endorse all that he says in their praise. Their work has necessarily involved fatigue and exposure, and the way in which one and all, Europeans and Egyptians alike, have devoted themselves to their duty, is beyond all praise. I think they well deserve the thanks of the Government of His Highness the Khedive. Mr. Willcocks' own work speaks for itself. Whatever may be the decision finally arrived at regarding his proposals, I think there can be but one opinion regarding the ability he has shown in the preparation of this project, and the manner in which he has considered and thought out every detail.

The Technical Commission.

Taking into consideration the magnitude of the reservoir projects, we have asked that a commission composed of three of the most eminent hydraulic engineers in Europe be appointed for the purpose of considering the several schemes, and advising the Egyptian Government as to which of them should be adopted. We have further requested that the members of this technical

commission should come to Egypt next February, personally visit the different proposed sites, examine the designs and estimates, and then submit their views to the Government.

We have asked for this Commission, not from any want of confidence in ourselves or in our staff, but considering the gigantic nature of the work and the vastness of the interests involved, we have preferred subordinating our judgment to that of men justly celebrated for their mastery of all subjects connected with Hydraulic engineering. Once then that this commission has pronounced its opinion, the Government will feel certain that it is not embarking upon an enterprise which may well be termed colossal, without having obtained the best scientific opinion upon it available.

Questions to be considered by the Technical Commission.

The questions to be considered by the technical commission are as follows: —

1. The proposal to construct a dam at some point of the Nile between Wadi Halfa and Cairo, and to form a storage reservoir in the valley of the river itself.

2. The proposal to construct a storage reservoir in the Wadi Rayyan depression in the desert.

3. An examination of all the designs, plans and estimates prepared by us for the different projects.

4. An opinion as to whether the sanitary condition of the country will be affected in any way by the storage of such a body of water as is now proposed.

5. A selection from among the different projects which have been submitted for the information of the Egyptian Government.

Questions to be considered by the Public Works Department.

Besides the matters referred to the technical commission there are others of great importance connected with this project which we propose taking in hand departmentally: —

1. The method of utilising the extra water stored in the reservoirs.

2. The works rendered necessary in Upper, Middle and Lower Egypt for the utilisation of the water.

3. The effect on Upper Egypt of a complete or partial suppression of the basin system and its replacement by perennial irrigation.

4. The effect on the Nile in Lower Egypt of the suppression of the Upper Egypt basins.

Appendices XI and XII.

On these latter points, I have asked Major Brown and Mr. Foster, the Inspectors General of Irrigation in Upper and Lower Egypt respectively, to give me their opinions. Their views are embodied in their notes which I have added to Mr. Willcocks' report as appendices XI and XII.

The first question we have to consider is the amount of water to be stored to increase the agricultural yield of the country and bring waste land into cultivation. The second is whether this water is available in the river, and if so, at what period.

Amount of water required. Report page 6. Appendix XI. Appendix XII.

To facilitate reference, I divide Egypt into three parts: —

Upper Egypt, or the country south of Assyût.

Middle Egypt, or the country between Assyût and Cairo.

Lower Egypt, or the country north of Cairo.

As no revenue survey has ever been made of Egypt, it is difficult to arrive at exact figures about the land which it is proposed to irrigate.

In Upper Egypt, Mr Willcocks and Major Brown are practically at one in their estimate of the area. I agree with Major Brown in accepting Mr. Willcocks' figures as they are slightly the higher of the two. The area of this portion of the country may then be considered as 1,200,000 feddans. Both agree as to the quantity of water required per feddan, and consequently I am again in accord with Major Brown in choosing Mr. Willcocks' figures as being higher than his for the total of water required.

On pages 7 and 9 of Mr. Willcocks' Report are to be found in detail, the amount of water required per diem per feddan commanded, the total discharge required, and the amount of water available in the river at its lowest and in years of minimum supply. A comparison is then made between the quantities available and required; and the amount of deficiency, which the reservoir would have to make good, is calculated.

For Upper Egypt, the total quantity needed to be stored is 1,160,000,000 cubic metres (see paragraph 19).

In Middle Egypt, there are again slight differences between Major Brown's and Mr. Willcocks' figures and again I select the higher. These figures are given in para. 19 of the report and amount to an area of 1,200,000 feddans and a total of 950,000,000 cubic metres of water needed to be stored for the requirements of the country between Assyût and Cairo.

On referring to the details of requirements, it will be noticed that the period during which water will be taken from the reservoir differs slightly for Upper and Middle Egypt: for the former it is fixed as between the 1st March and the 15th July, whereas for the latter the dates are from the 1st April to the 31st July. This has its explanation in the different climatic conditions of the two regions: the further south we go, the higher is the temperature, and the earlier the demand for the increased water supply. Again, the relief afforded by the arrival of the early flood is felt sooner in Upper than in Middle Egypt, which latter more nearly approaches Lower Egypt in its agricultural conditions.

In Lower Egypt, there is no great difference between the area of cultivated land as given by Mr. Willcocks in para. 8 of his report and by Mr. Foster on page 5 of his note. The former makes it 2,740,000 feddans, and

the latter 2,807,803 by including partially cultivated lands near the sea. We may then in round numbers take the cultivated area at 2,810,000 feddans. In addition to this, there is the area of waste and salted land, known as the "Birrya", at present unculturable, and covering an extent of some 1,200,000 feddans. Of this area, Mr. Willcocks in para. 10 estimates that half, or 600,000 feddans, might be brought under cultivation by an increased water supply in summer. I consider the above as the very outside that is likely to be reclaimed for many years to come. To keep his total the same as Mr. Willcocks, Mr. Foster assumes this Birrya land at 530,000 feddans and eventually gets his total area as:—

Cultivated	2,810,000	feddans
Waste land to be reclaimed	530,000	»
TOTAL....	3,340,000	»

As to the quantity of water required, Messrs. Willcocks and Foster agree very closely in the total, although they differ in details. The following are the comparative quantities of water needed te be supplied by the reservoir as calculated by them: —

	QUANTITY REQUIRED ACCORDING TO MR. FOSTER.		QUANTITY REQUIRED ACCORDING TO MR. WILLCOCKS.
April	37,500,000	cubic metres	70,000,000
May	275,000,000	»	280,000,000
June	495,000,000	»	330,000,000
July	744,000,000	»	820,000,000
TOTAL.....	1,551,500,000	»	1,500,000,000

The difference between these figures is 3 $^1/_2$ per cent. — Since Mr. Foster's figures are the higher, I accept them.

For the whole of Egypt, we therefore need a reservoir with a storage capacity of:

Upper Egypt	1,160,000,000	cubic metres
Middle »	950,000,000	»
Lower »	1,551,000,000	»
TOTAL. ...	3,661,000,000	»

If Upper Egypt be omitted for the present, we need a reservoir for Middle and Lower Egypt with a storage capacity of 2,501,000,000 cubic metres.

It must be remembered that the above figures have been worked out from the discharges of the river in a year of exceptionally bad summer supply like that of the years 1874, 1878, 1889 and 1890. These four years were the only ones in the last twenty in which the summer supply fell abnormally low; and consequently during the remaining sixteen years there would have been, with the reservoir in existence, a supply of water considerably in excess of requirements if we even included the reclaimed area. Questions may legitimately be

asked as to the utility of making the reservoir of greater capacity than that which would be needed in sixteen years out of twenty. My reply is that:—

1st, we cannot calculate that the proportion of years of low and high summer supply will always be constant.

2nd, that as cultivation improves and expands, the damage done to public and private interests would be proportionally greater in the future than at the present time, when we cannot consider the crops as absolutely protected against drought.

There is yet another reason why, in my opinion, we should endeavour to have a surplus supply of water available. It would be possible to turn this surplus down the Rosetta and Damietta branches of the Nile during the period of extreme low supply, when the Barrages would be otherwise hermetically closed, and when in consequence the sea water would run up the mouths of the river for a considerable distance just as it does at present. It is difficult to ascertain from the statistics of the mortality in the towns of Lower Egypt whether the death rate has really increased during the months of June and July in the towns situated upon the Nile since we first took to regulating seriously at the Barrage. It was in 1886 that we began this extreme regulation, and previous to that year statistics are not easily obtainable. I tabulate here the best information I have been able to get, of four towns in the Delta on the Branches of the river, and three towns in the Interior. The death rate is calculated on the census of 1882, though in all the towns, except Rosetta, there has been a steady increase of population.

Mortality during June and July.

Towns situated on the River.	MEAN DEATH RATE PER 1000 ON THE CENSUS OF 1882 FOR THE YEARS 1880-1885	MEAN DEATH RATE PER 1000 ON THE CENSUS OF 1882 FOR THE YEARS 1886-1892	INCREASE	DECREASE
Benha	62.7	48.1	..	14.6
Mansura	51.4	62.7	11.3	..
Damietta	24.4	27.0	2.6	..
Rosetta	20.8	17.4	..	3.4
Towns in the Interior.				
Shebin el Kom	53.4	65.4	12.0	..
Tanta	62.7	67.4	4.7	..
Zagazig	49.9	53.5	3.6	..

Not much can be gathered from the foregoing. The towns situated upon the River have alone experienced the effects of the low supply; and of them, two have apparently had a fall in their death rate, while one of the two where the rate has risen is Damietta, which has been supplied by Government with a large cistern, from which the greater part of the town gets its water supply. The death rate of the three towns in the Interior has apparently risen since 1886, and yet in each case the water supply has been considerably increased in this

interval. With these figures before us, it is difficult to accept the fact that the cutting off of the supply in the two Branches has caused any large increase in the death rate, more especially when we consider that no account has been taken of the steady increase of the population.

I am far from saying that no inconvenience has been caused by our reducing the supply in the river in order to increase that for irrigation, but his inconvenience has been trifling in comparison to the gain to the towns and villages that have profited by an increased supply in the canals. I think however that we should try, if possible, to remove this inconvenience by increasing the storage capacity of our reservoirs, and insuring a supply being passed down each branch of the river even during the years of low supply. In years of ordinary and good supply, I have shown that we shall have this supply available. Sir Colin Scott Moncrieff in his note on "Nile Reservoirs" allowed for a volume of 5,000,000 cubic metres per day being passed down the two branches. We may take the period of low supply as 50 days. To allow for this extra storage of 250,000,000 cubic metres of water, we should have to add from L. E. 120,000 to L. E. 200,000 to the estimated cost of the reservoirs, according to the site selected.

If however we consider the reservoirs lying between the first and second cataracts, we have, I think, at hand an additional storage area which will suffice for these extra requirements. Throughout the whole of this reach, great ravines (known locally as "Khors") run up through the hills on either side. Many of these are of very considerable sectional area and extend to a distance of several kilometres from the river. The capacity of these khors has not been included in that of our reservoirs and yet it would amount to a very considerable figure. I estimate that it would suffice to supply the extra water needed for the two branches of the Nile downstream of the Barrage. In our estimates, we have also allowed for a considerable enlarging of our riverain canals on both branches. This enlargement will directly benefit the Towns on the river.

Supply of water available for filling the reservoirs. Report page 15.

Mr. Willcocks, in page 15 and 16 of his report, gives figures to show the amount of water available in the river for storage purposes even in years of very low supply. If the reservoir selected be in connection with a dam in the Nile valley, the months during which water would be taken from the Nile would be those after the passing of the flood, viz: November, December and January. Making an allowance of 1000 cubic metres per second for navigation, which is considerably in excess of the requirement of irrigation, Mr. Willcoks estimates that (1) 6,100,000,000 cubic metres could be stored after the flood in a year of bad supply. This amount is nearly double that needed for the whole of Egypt.

(1) Since the above calculations were made, the discharges of the Nile on a falling gauge have been tabled. These figures are in consequence reduced to 5,000,000,000 cubic metres. This amount is however more than ample for our requirements.

As regards the Wadi Rayyan project, it would at any rate during its period of first filling take its supply from the river during the time of highest flood; when it was once filled it could under certain conditions be fed yearly from the Bahr Yusuf, which, with the help of a dam at Assyût, could carry a largely increased discharge. The figures before given are then equally applicable to the supply available for the Wadi Rayyan, which having only to serve the country to the north of Cairo, would require to store only sufficient for that area. We may therefore safely assume that for either project there would be abundance of water always available for storage.

Gain to the country on the introduction of perennial irrigation. Appendix XI. Appendix XII.

The gain to be obtained by the introduction of perennial irrigation would be of two kinds :—

(1) Direct gain to the State from the sale of the reclaimed lands and the increase of the annual revenue derived from them.

(2) Indirect gain to the State, but direct gain to the country, resulting from the increased value of the agricultural produce, the rise in the price of land, and in the land rents. There would in all probability be a considerable increase in the Customs revenue owing to the increased wealth of the country, while new industries would probably spring up to meet the requirements of the increasing population.

Direct gain to the State.

(1) The direct gain to the State as shown by Major Brown and Mr. Foster in Appendices XI and XII would be on :—

40,000	feddans	in the Fayoum Province.
10,000	»	in Giza Province.
530,000	»	in the northern Provinces.
580,000	feddans	in all.

Mr. Foster estimates the maximum sum that may safely be estimated for as obtainable from the sale of the lands in Lower Egypt at L.E. 200,000 only, as the purchasers would have to spend considerable sums in reclamation. This sum, at 4 per cent, represents a steady addition to the revenue of L.E. 8,000. As regards increased revenue from taxation, it is certainly taking a moderate view if we estimate the tax per feddan at 50 piastres on 540,000 feddans. The total for Lower Egypt would be therefore :—

Sale of lands	L.E.	8,000	per annum.
Increased taxation	»	270,000	»
TOTAL.....	L.E.	278,000	per annum.

In Middle Egypt, Major Brown points out that, the Daira Sania being a Government Estate, the State itself would be a large gainer. He estimates the rise in annual rents of this administration at L.E. 400,000 per annum. He further remarks, and with justice, that the basin lands, which at present pay a lower rate of taxation than those receiving "Sêfi" irrigation, should on reaping the same advantages, pay the same taxes. This I consider perfectly fair. The 485,835 feddans of basin land, if taxed at an additional 30 piastres per feddan, would bring in an annual revenue of L.E. 151,750. Lastly the 40,000 acres of reclaimed land in the Fayoum would pay a tax of L.E. 20,000 per annum. The direct annual gain to the State for Middle Egypt becomes therefore :—

Increased revenue Daira Sania lands......	L. E. 400,000	par annum.
Basin lands taxed as "Sefi".............	» 151,750	»
Reclaimed land in the Fayoum...........	» 20,000	»
TOTAL.....	L. E. 571,750	»

From Upper Egypt I allow for no direct gain to the State. It is true that the taxes of the basin lands might be raised, but I do not consider this to be advisable.

This tract is, on the whole, the poorest part of Egypt and is under very special conditions as to climate and distance from a sea-port.

Adding up the direct gains of Middle and Lower Egypt, we obtain a yearly increase to the State of L. E. 850,000, equivalent, at 5 per cent, to capital of L.E. 17,000,000.

Direct gains to the country.

(2) The gain to the country.

The following estimates are liable to modification by a fall in the prices of produce. They are based on present prices.

Major Brown and Mr. Foster have worked out these figures in great detail, and I would refer any one desiring further information on the subject to their notes. The former says : "When there is an increased supply from a reservoir, the value of ordinary "Sêfi" land will increase from L.E. 30 to L.E. 40 per feddan and rents will rise from L.E. 3 $^1/_2$ to L.E. 5 per feddan, while the yield of the land will increase from L.E. 7 to L.E. 9 per feddan. The basin and "Sahel" figures will also rise to the same as the increased figures for ordinary "Sêfi" land".

Major Browns' figures for Upper Egypt are :—

	AT PRESENT.		FUTURE ENHANCED VALUE.		INCREASE.
Value of land............	L. E. 12,915,960	—	L. E. 35,965,300	—	L. E. 23,049,340
» yearly rental.......	» 2,666,450	—	» 4,110,320	—	» 1,443,870
» yearly produce.....	» 3,583,385	—	» 8,220,640	—	» 4,637,255

Middle Egypt :—

	AT PRESENT.		FUTURE.		INCREASE.
Value of land............	L. E. 20,426,400	—	L. E. 43,575,240	—	L. E. 23,148,840
» yearly rental.......	» 3,159,998	—	» 5,506,905	—	» 2,346,907
» yearly produce.....	» 5,178,786	—	» 9,864,429	—	» 4,685,643

The above figures are startling. Major Brown has however very great experience in agricultural questions in Upper Egypt and has had special opportunities of studying them. He has shown in his note in considerable detail how the figures upon which he bases his estimate have been arrived at. Even allowing that the eventual results may not quite bear out his anticipations, his figures are so high that a very considerable deduction might be made from his totals and yet leave an exceedingly large margin of profit to the country.

Mr. Fosters' totals for Lower Egypt are much smaller than those for Middle and Upper Egypt, as the greater portion of the former is at present perennially irrigated. His estimates are for increased value of annual produce alone : —

		PER ANNUM
Increased value of the cotton crop................	L. E.	380,000
Increased value from Sêfi lands not at present under summer cultivation............................	»	975,000
Increased value of the rice crop..................	»	660,000
» » » winter crop................	»	795,000
» » » maize crop................	»	480,000
TOTAL.....	L. E.	3,290,000

It must be remembered that in thus estimating the probable gain to the country, both in Upper and in Lower Egypt, we are dealing with the eventual increased value. This increase will not be felt at once, but will take years to arrive at. In Upper and Middle Egypt, the gain will be more quickly felt than in Lower Egypt, as the transformation of the system of cultivation will be greater and will take much less time.

Different projects considered by Mr. Willcocks in his report.

The different Reservoir projects are discussed in paragraphs 38 to 83 of Mr. Willcocks' report. They fall under two heads : —

(1) A dam across the Nile at a suitable site, with the valley of the river itself as the storage reservoir.

(2) The filling of a depression in the deserts from the Nile in flood and using it as a storage basin. To the former class belong the Kalabsha, Philæ Assuân cataract and Silsila projects; and to the latter the Wadi Rayyan scheme, which has for years been so persistently urged upon the Government by Mr. Cope Whitehouse.

Paragraph 36 of the report contains a history of the Reservoir question. So long ago as 1873, the distinguished French engineer, Linant de Bellefonds Pasha, suggested the Silsila gate of the Nile as a suitable site for a regulating weir; it was another Frenchman, Count de la Motte, who further developed the idea and proposed a reservoir dam at the same site. Owing to financial difficulties, however, nothing was done until 1889 when Mr. Prompt, the French

member of the Egyptian Railway Board, pressed upon the Government the necessity of studying the question. Mr. Willcocks was then deputed to take up the project as a whole, not only as regards Gebel Silsila, but also as regards the entire Nile valley between the 2nd Cataract and Cairo. This report is the results of his four years' study.

Proposed type of dam, and the question of the silting up of the reservoirs. Report page 10.

Hitherto all proposals for reservoirs have been based upon designs for solid dams to store up the muddy waters of the Nile flood. Mr. Willcocks' design differs essentially from the previous ones. He proposes a dam provided with numerous and very large undersluices which would pass the entire flood waters, heavily charged as they would be with deposit. The closing of these undersluices for regulation would not begin until the flood had passed. Mr. Willcocks claims that only by this method can the reservoir be prevented from gradually silting up. Lt. Col. Ross, in his note written in 1891, fully endorses Mr. Willcocks' views, and adds that any system of solid dam, through which the flood waters cannot pass, with practically a full and unimpeded waterway, will inevitably lead to the certain diminution of its storage capacity and the eventual silting up of the reservoir. With this opinion I am entirely in accord. The Nile during the month of August, September and October is heavily charged with solid matter in suspension (see page 12 of the Report). Any obstruction, like a solid dam, which would interfere with its flow and check its velocity during flood, would cause a very heavy deposit of silt upstream of the work. No ordinary scouring sluices could be effectual enough to keep such a channel clear. The only effective method is to allow the Nile flood a free passage.

Mr. Willcocks, on page 11 of his report, gives instances of solid dams in existence, in which the scouring sluices have failed to prevent the silting up of the reservoirs. In India, we have had much experience of these facts. If Algerian and Indian torrents have been able to completely fill up reservoirs with deposit, we may reasonably conclude that the Nile, with its high floods which last for three months per annum, and are heavily charged with mud, will most certainly do the same.

It is true that during the months of November and December in low years, and December and January generally, when the regulating gates will be closed and the reservoir allowed to fill, there will still be a certain amount of matter in suspension in the river. It is however so insignificant in quantity as compared with the amount existing in flood that I think it may be neglected. Any silting that would take place upstream of the dam under these conditions would be, in my opinion, very gradual and very limited in amount, and would in all probability disappear on the opening of the sluices in flood. If the deposit could not be removed, its accumulation would be so slow that I think it is hardly worth taking into account as an objection to the dam.

Objections however may be, and indeed have been made, against any dam for storing water in the Nile valley itself. The principal ones that have been formulated are: — **Possible objections to dams in the valley of the Nile.**

1. That its construction presents insurmountable engineering difficulties.

2. That, from a strategic point of view, it would be unadvisable to expose Egypt to the danger of having its summer water supply suddenly cut off by a hostile force seizing the dam.

3. That an earthquake, or even faulty construction, might expose it to an accident which would cause such a flood in the river as to sweep away every vestige of civilization from the site of the dam to the apex of the Delta.

4. That the water stored in the reservoir would be stagnant and become polluted, and thus be capable of poisoning the water supply of Egypt.

I shall consider these objections in detail. **Alleged difficulty of construction of the dams.**

1. It may be admitted that a dam of the kind now proposed, if built in a river like the Nile, would be a work of great magnitude; greater as regards its length and its power of control than any similar work hitherto attempted. In height however it would be surpassed by many dams in existence (see appendix I and pages 10 and 11 of the Report). Its great length would certainly increase the number of possible weak points, but beyond that it would be in no way more dangerous than dams of greater height and less length. The pressure against the work would be dependent on its height and not on its length, and as before remarked its height would not be extraordinary. There would also be the question of the foundation on which it would be constructed. Fortunately for the stability of the work, it would be founded on solid granite, or sandstone *in situ*; it would be built with exceptionally good building materials, and with the most liberal supervision. Under these conditions, I cannot accept the fact that the engineering difficulties are insurmountable; I go further and say that these difficulties will be found to have been greatly exaggerated and to have been no greater than those which have so often been successfully overcome by Hydraulic Engineers.

2. The strategic side of the question hardly comes within the scope of discussion from the engineer's point of view. It is for the military and political advisers of His Highness the Khedive to consider and decide whether this danger be imaginary or real. For my own part, I can hardly imagine the possibility of Egypt existing as a State and yet not holding complete command of the frontier between the 1st and 2nd cataracts. With this frontier in hostile hands, it seems to me that the subjection of Egypt itself would soon follow, and under these circumstances the loss of one summer's water supply would be a comparatively minor evil. **Alleged strategic disadvantages of the dams.**

Alleged anger from a failure of the dam.

3. The possibility of the failure of the dam is a perfectly legitimate criticism, and one which would naturally be made by any one who had to consider the project. As regards failure by an earthquake, this is a risk run by every great engineering work in the world. The risk of destruction by design or violence comes under the same category. If the dam be built, it will of course be properly guarded, and the contingency of its destruction need hardly be discussed.

With respect to the failure of the dam by reason of its own instability or inherent weakness, I can only say that we submit our designs and calculations to the opinions of the eminent engineers of the technical commission, who will advise the Egyptian Government on this matter. Once the design is approved, we shall insure, as far as lies in our power, that the work be built with the most reliable materials and with minute supervision of each and every detail of construction.

It might still be urged that, in case of failure, the risk of disaster to the country would be so great that it ought to outweigh every other consideration. In my opinion however, this risk would not be so great as it might appear to be at first sight: and even, if the dam were to fail, the damage done to the country would be comparatively small, although there might be great but temporary inconvenience and pecuniary loss.

It is quite true that dams have failed and resulted in great loss of life and property, but in every case there has been some reason for the failure, such as inferior foundations, faulty designs, or weak materials used in construction. Dams which have been founded on sand and clay, on sandstone, and on inferior limestone have at times failed; but I know of no instance of failure of a work built upon a sound granite bed and constructed of massive blocks of granite put together on sound mathematical principles. Thus founded and thus built, no failure should be possible, and even if it were it would be local and confined. No comparison can be made between its failure and the failures of earthen dams or dams built on weak foundations. The granite at Kalabsha and at the Assuân cataract, standing in the position it does, warrants its ability to support any pressure of water and to provide a perfect foundation. The massive granite blocks of the superstructure laid in hydraulic mortar and cement promise to be almost as strong and as lasting as the natural rock itself. The failure, if there were any, would be confined to a single opening or group of 10 openings, that is to say to a length of 47 metres of the dam. Each such length would be flanked by solid abutments of great strength, which are provided in the designs, and which would be capable of resisting any shock. The height of the dam, where it is pierced with sluices, and where an accident would first occur, would be 22 metres and its breadth 16 metres, and a section which failed could not be carried away in a moment or even in a season. The greater portion would lie where it fell, forming an obstacle to the water, and preventing any sudden

escape. I do not think that anything short of an earthquake or an explosion of dynamite could shake the massive abutment piers. Even were an earthquake to shake the whole structure, it would only fissure it, and cause portions to fall in, without bringing down the whole; since each running metre of the dam has been designed as strong enough to hold up the maximum head of water independently of any lateral support and of any tensile strength in the mortar itself. I maintain then, that if the work were seriously shaken by an earthquake, occasional huge masses of masonry might fall down, but they would remain where they fell and create another cataract over which the water of the reservoir would escape by degrees.

It must not be forgotten that were an accident to occur, it could only occur when the reservoir was full, or being filled; it would occur therefore in winter or summer when the river was very low. A glance at the cross sections of the Nile valley between Assuân and Cairo will show how insignificant will be the summer section of the Nile, even when it is increased by the discharge from the reservoir, as compared to the sectional capacity of the river itself. The trough of the Nile valley between Assuân and Cairo could accomodate 7,000,000,000 cubic metres, while a Nubian reservoir would have a length of some 300 kilometres, a head of water of 22 metres, and a maximum capacity of 3,600,000,000 cubic metres.

If we suppose the extreme case of an earthen dam at Assuân holding up 22 metres of water and failing suddenly, we can calculate from our observed sections and discharges that 160 kilometres of the Nile valley south of Isna would be inundated, but the maximum rise at Cairo would hardly be 5 metres or 19 pics on the Roda gauge. This would be an extreme case, and even then it would be tempered by the bar to the progress of the water offered by the narrow Silsila gate of the Nile. This gate would throttle the sudden escape of the water and greatly reduce the volume, while it lengthened out the time. With a masonry dam built on a granite foundation, such an accident would be almost an impossibility. The failure of a group of undersluices might result in the Assuân gauge rising to a maximum of 10 pics, and the Cairo gauge to a maximum of 15 pics. I quite allow that, were a limited portion of the dam to give way, there would be a certain amount of damage done by the loss of the portion of the summer supply, but the damage would be reparable; and the risks of its occurring are so small that, in my opinion, they are completely outweighed by the great benefits which would be conferred on the country by the construction of such a reservoir.

Alleged pollution of the water of a Nubian reservoir.

4. I have now to consider the contingency of the water stored becoming stagnant and injurious to the public health. It is argued that the water in the reservoir being stationary, and Nile water in May being poisonous and containing organic germs dangerous to human life, germs of disease

would be developed under a tropical sun. I answer that in the first place, the term stagnant is a misnomer. A reservoir with a minimum discharge of 50,000,000 cubic metres per day, which is equal to 20,000 cubic feet per second, and is in excess of the maximum discharge of the Rhone at Geneva, (which is 18,000 cubic feet per second), can hardly be called stagnant. There will be a constant flow through the whole body of the water stored. In the second place, I remark, that those who assert that the Nile is poisonous at Khartoum in May, appear to forget that, poisonous or not, this water has always been, and is to-day the only source of water supply to Egypt.

The water in the reservoir would be stored at a time when it is was perfectly pure, it would have a very great depth, and be constantly flowing. When the so called poisoned water entered the reservoir, I contend that it would be so diluted by its mixture with the immense body of pure water into which it would be discharged, that, if anything, its deleterious influences would be rather diminished than increased. M. Charpentier de Cossigny in his work entitled "Hydraulique agricole" (Encyclopèdie des Travaux publics) discusses the question of depth of water in reservoirs in its relation to the prevention of pollution of the water, at considerable length, and is of opinion that it is only in shallow tanks that this pollution is to be dreaded.

If bacteria could be produced by the medium of the hot sun upon the water, regardless of its depth, then it appears to me that the objections made to the Nubian dams upon this score would be equally applicable to the Wadi Rayyan project. In this latter, case there would also be a large body of water exposed to the sun's rays, and really stationary every year between the last day of filling and the first day of emptying. In the Nubian reservoirs, on the contrary, there would never be a single minute of the day when the great dam would not be discharging sufficient for irrigation and navigation.

Far from believing however that in either case the Reservoir water would be injurious to the health of the people, I am of opinion that their health would be benefited by the increased supply both in the river and in the canals.

As regards the possibility of damage to the country north of the dam by percolation resulting from the great differences in water level at the dam itself, one has only to inspect the proposed sites to see that this could not possibly occur.

…eneral …cription the dam …posed by …Willcocks. …eport …ge 13.

On pages 13, 14 and 15 of the Report, is a clear description of the general lines followed by Mr. Willcocks in designing his dam, and of the method of regulating it. I need not then do more than very briefly allude to this part of the subject, more especially as at every stage throughout the period of preparing his designs, Mr. Willcocks has conferred with, and consulted me. No single important detail has been finally decided upon until we have come to a complete accord. I accept my share of responsibility for the production of these designs, and submit them to the consideration of the technical commission with this understanding.

The proposed dam is a solid wall of granite masonry pierced by 100 or 120 openings or undersluices, provided with regulating gates. The total area of waterway allowed is from 2000 to 2400 square metres, calculated to pass a mean high flood at Assuân of 10,000 cubic metres per second with a mean velocity of 5 metres per second and a head of 2 metres. In the case of an exceptional flood amounting to 14,000 cubic metres per second, the mean velocity would rise to 7 metres per second and the head to 4.25 metres. A flood of this volume, which is the highest known, is exceedingly rare, occurs two or three times in 20 years, and for a few days only on a quickly rising Nile. The undersluices, lined as they will be with massive blocks of granite ashlar, will be perfectly capable of standing such velocities.

Each undersluice will be 10 metres high and 2 metres wide. Mr. Willcocks strongly recommends that the regulation be performed by means of Stoney's patent self balanced roller gates. I have personally inspected gates of this type working in England, and am in entire accord with Mr. Willcocks. They are, in my opinion, the best type of regulating gates yet designed, and I know of no others which could be successfully worked in openings of this size subjected to such considerable heads of water. Appendix IV contains a report by Mr. F. G. M. Stoney on the gates proposed by him for the undersluices. I hope to have a gate of this type set up and in working order in this country before the arrival of the technical commission.

A chief feature of the dam as designed by Mr. Willcocks is the placing of these undersluices at varying depths. The varying levels of the rock in the bed of the river lend themselves to this design, which insures that no gate will be worked under the extreme head upon the dam. At the time of closing, the lowest gates will first be shut; and, as the water rises, the gates at a higher level will be lowered. At the time of opening, the process will be reversed, and the highest gates will first be opened; and, as the water falls, the gates at a lower level will be raised.

The dam will be solid wherever the depth of water in the reservoir is more than 32 metres. No undersluice will have its sill more than 10 metres above the living rock under its own base.

The dam in plan will be generally built on a curve after the pattern of the great French dams. It will be provided with massive abutment piers, 10 metres in thickness, at intervals of 57 metres centre to centre. These piers will add strength to the work, and help to localise an accident if it should ever occur.

Navigation will be provided for by a separate lock channel furnished with locks, capable of passing our river steamers. Mr. Willcocks' designs show a double lock with a total lift of 25 metres divided into 12 and 13 metres. I think this would necessitate gates of unworkable dimensions, and I prefer having four locks, with no lift greater than 6.50 metres. Mr. Willcocks has allowed for this in his estimates.

The different sites for the dams discussed. Report page 18. Appendix VII.

I now come to the most difficult, and certainly the most important, part of my task, viz : the responsibility of recommending to the Egyptian Government, the selection of one particular reservoir in preference to the others. Last November, accompanied by Mr. Willcocks, I inspected all the different sites, and the observations which follow have been compiled from notes made on the spot. Before commencing my remarks on the different reservoir sites, I think I ought to state why it is that the second or Wadi Halfa cataract has not been included in the number of our proposals.

The second cataract, or rather series of cataracts, stretches for a length of 200 kilometres between Dal and Wadi Halfa along the Batn-el-Haggar (see Appendix III page 5). The total fall of water surface is 66 metres. It is owing to this excessive fall that any dam constructed within the Batn-el-Haggar would have to be excessively high in order to store the amount of vater required for irrigation. The only point in this reach, at which a dam holding up a large volume of water might be constructed, is its southern extremity, Dal, which is beyond the existing Egyptian frontier and beyond our power of studying at present. We are therefore compelled to omit it from the number of possible sites, at any rate as far as the present project is concerned.

Kalabsha site. Report page 24.

I begin with the site most to the south, and work northwards. At the Kalabsha gate, the Nile passes through a channel some 150 metres in width, and 30 metres in depth at the time of low supply. Here of course, owing to the permanent depth of water, any construction of a dam is practically impossible. About 2 $^{1}/_{2}$ kilometres further south, the river is wider and divided into several channels, in all but one of which the water in summer is not more than 9 metres in depth. At this spot, we have a good site upon which to construct a dam. The rock is everywhere granite of good quality except on the extreme left flank where we have a hard and compact diorite. The only weak point at this site is the depth of water in the right hand channel, which would render construction difficult. Soundings disclose rock generally at a R.L. of 78 metres, though in places it is as low as R.L. 74. Since the minimum summer level is R.L. 93, it would be necessary to get in the foundations under a head of 19 metres of water. The total length of this deep portion is only 100 metres, and the rock is apparently sound and good. I know that it is possible to succesfully put in foundations by means of compressed air at greater depths than 19 metres, but I confess, that when I contemplate the importance of the work and the pressure which would come on it, I prefer insisting on the entire length of foundation masonry being built in the open and capable of easy inspection. Under these conditions, we should need very massive cofferdams for this portion of the work. The cofferdams would be costly and difficult to manage, and its is the great depth of water in which they would be placed which constitutes the principal objection to the Kalabsha site. A sum of L.E. 250,000 has been entered in the estimates

for cofferdams. A reference to the plan will show that neither on the upstream nor on the downstream side of the proposed site is there a line across the river which does not encounter a channel as deep as the deepest point in the site itself.

I have requested Mr. Willcocks to have some borings made in the river bed at the proposed site and to the south of it. These borings will be completed before the arrival of the technical commission: I have little hope however of finding sound rock at a level much above R. L. 74.

Kalabsha is some 50 kilometres upstream of the Assuân cataract, and consequently the crest of a reservoir dam at the former site must have its reduced level considerably above that of a dam at the latter site if the two reservoirs are to contain the same volume of water.

According to Mr. Willcocks' calculations a dam at Kalabsha works out as follows:—

AREA IRRIGATED	R. L. OF WATER SURFACE IN RESERVOIR	CAPACITY OF RESERVOIR IN CUBIC METRES	COST
Lower Egypt......................	114.00	1,560,000,000	L.E. 1,250,000
Lower and Middle Egypt...........	118.00	2,510,000,000	» 1,600,000
The whole of Egypt................	121.00	3,670,000,000	» 2,000,000

An allowance of 1 metre or 5 per cent has been made for evaporation.

I think that the very utmost limit of safety at Kalabsha, as regards the height of the dam, is to be found at R. L. 118,00^{m}. This gives a height of 44 metres from the crest of the dam to the lowest point of the river bed. In my opinion, therefore, we have at Kalabsha a site where we might construct a dam which would create a reservoir capable of supplying water to the country north of Assyut. Beyond this, I consider it dangerous to raise the height of the reservoir dam. I propose therefore, that, if Kalabsha be the site chosen, the dam be raised to R. L. 118,00, and the requirement of Middle and Lower Egypt be met for a sum of L.E. 1,600,000.

I may note that, in the estimated cost of L. E. 1,600,000, a sum of L.E. 432,000 has been included for compensation for lands and villages inundated by the reservoir. The inundation will reach from Kalabsha to Toski, and the compensation has been estimated from figures supplied by Wodehouse Pasha, the late Commandant of the Frontier.

The reservoir site to the immediate north of Kalabsha is the one called "Philæ" in the report. The alignment selected is a little to the south, or on the upstream side of Philæ island; and a dam built here would leave the celebrated temple untouched. Mr. Willcocks has two alternative lines, but though they traverse sound and compact granite on the greater part of their length, both pass through schists and inferior gneiss on their extreme right. Borings have been taken

Philæ site. **Report page 22.**

in the right channel of the river and have gone down as low as R.L. 75 without coming on the sound rock. In spite however of the fact, that the rock on the right bank is of such inferior quality that I consider it not well calculated to stand extreme pressure, I feel a reluctance in absolutely rejecting this site. I have ordered further borings to be made to find out, if possible, the depth at which sound rocks exists, though everything points to this depth being so far below summer water level as to render the construction of the foundation masonry practically impossible. It is with the greatest regret that I feel compelled to relinquish the idea of this project being a good one, as the storage area would provide enough water for the requirements of the whole of Egypt and yet leave Philæ temple untouched.

According to calculations, a dam at Philæ works out as follows:—

AREA IRRIGATED	R.L. OF WATER SURFACE IN RESERVOIR	CAPACITY OF RESERVOIR IN CUBIC METRES	COST
Lower Egypt.	110.00	1,560,000,000	L.E. 1,500,000
Lower and Middle Egypt.......... .	114.00	2,510,000,000	» 1,750,000
The whole of Egypt...............	118.00	3,670,000,000	» 2,100,000

All allowance of 1 metre or 5 per cent, has been made for evaporation.

I prefer the project for Lower and Middle Egypt. The R.L. of 114 inundates only the valley from Philæ to Korosko, and leaves the country south of Korosko untouched. The compensation for lands and villages between Philæ and Korosko amounts to L.E. 350,000 and has been allowed for in the estimates.

Assuân Cataract site. **Report pages 21 and 36.**

I now come to the discussion of that portion of the project about which much has been said and written: I mean the proposed dam at the head of the cataract itself, which would necessitate the drowning of Philæ temple for several months each year, or its removal on to another island.

From a personal inspection of the cataract, I can well understand Mr. Willcocks' enthusiastic advocacy of the site. For the purpose of constructing a dam it is almost perfect. The rock throughout is, as Mr. Willcocks says, a hard and compact syenite or quartz diorite, except at the extreme left of the main channel, where the quality is not so good, though it is even here compact and capable of resisting the greatest pressure. A reference to Mr. Willcocks' plan of the cataract (Plate N° 8) shows how wide and shallow is the section of the river, and how easy it would be to put in the foundations of a dam. The river in summer might be turned down one or more of the different channels, leaving the remaining ones dry. The foundations would thus be put in in the dry, which, in works for holding up water, is a consideration of the greatest importance. The rock again is so hard and compact that hardly any blasting, beyond pure foundation work, would be necessary. The lowest point of the river bed

found anywhere on Mr. Willcocks' proposed line of dam is at R. L. 83^{m}, or 7 metres below the summer level of the river, and this depth is found only on a length of 35 metres. The average depth of water in summer may be put down as 5 metres. Another great advantage of this site is that the whole of the undersluices would be built upon the dry reefs projecting above the level of the water in winter and summer. They would consequently be built in the dry, and as there would be 7 months per annum in which to work, there would be sufficient time to complete the floors, piers and abutments without any recourse to cofferdams and pumping.

The alignment chosen by Mr. Willcocks follows the shallowest section everywhere and never leaves the granite bed. It is a question whether it might not be more economical to select a shorter line, even though it necessitated working in deeper water, but the advantage of having one's work always above water level in the working season is so considerable, and so much more likely to insure first class work that I cannot recommend any change in the proposed alignment. The only point I do not approve of in the proposed arrangements is the line selected for the navigation channel. I think that the angle at which it enters the river below the dam is so sharp as to make navigation difficult. I myself prefer the extreme left hand channel of the river, and should like to see the locks constructed there. Some extra blasting would doubtless be necessary, but navigation would be far easier. The stone blasted from the line of the navigation channel could be used for building purposes.

I agree with Mr. Willcocks in considering the Assuân cataract (putting aside for the moment the question of the Philæ temple) as the site best suited for one of our reservoir dams, which is to be found north of Wadi Halfa. I personally should have no anxiety about the absolute stability of a dam erected there. Nowhere else do we find such advantages of site: sound rock, numerous islands, a wide section, and shallow water in which to work. These advantages have their effects on the estimate in reducing the cost of cofferdams and the price of masonry constructed above water level.

According to calculations a dam at the head of the Assuân cataract works out as follows : —

AREA IRRIGATED	R. L. OF WATER SURFACE IN RESERVOIR	CAPACITY OF RESERVOIRS IN CUBIC METRES	COST
Lower Egypt	110.00	1,600,000,000	L. E. 1,100,000
Lower and Middle Egypt	114.00	2,550,000,000	» 1,400,000
The whole of Egypt	118.00	3,700,000,000	» 1,700,000

An allowance of 1 metre, or 5 per cent, has been made for evaporation.

Unfortunately, with every advantage in its favour as to volume of water stored, soundness of foundation, and economy of construction, this site labours

under the objection (which I fear may be found insuperable) of having Philæ temple on its upstream side. No dam could be constructed on the cataract without inundating a great portion of this temple for several months every year. I agree with Col. Ross that no project, which has this effect, should be admitted, unless it were impossible to find a reservoir site elsewhere. We cannot say that there are no other possible sites. There are Kalabsha, Philæ and Gebel Silsila, which are all available, and we cannot therefore claim that if a dam has to be built, it must necessarily be built at the head of the 1st cataract and drown the temple of Philæ.

Admitting this fact to the full, I still consider the Assuân site to be so superior to any other, that if any means could be found for obviating the difficulty which attaches to this temple, I think the subject well worth the consideration of the Egyptian Government, even although it involved additional cost to the project. On page 36 of his report, Mr. Willcocks suggests the possibility of removing the temple of Philæ from its present site, taking it up stone by stone, and rebuilding it on the adjacent island of Bigeh, where it would be well above the highest water level of the reservoir. I cannot say whether it would be possible to do this without injury to the temple. If so doing would cause any injury, or alteration of any kind to it, I should recommend the abandonment of the Assuân dam altogether. Any work which caused either partial damage to, or the flooding of this beautiful temple, would be rightly considered by the whole civilized world as an act of barbarism. Moreover it would be an act not absolutely necessitated by the circumstances, for I repeat that we have other possible, though somewhat inferior sites, upon which to construct dams.

If the removal of Philæ temple is however only a question of expenditure, the subject at once commands attention. In this matter, I turn naturally to Mr. J. de Morgan, the able Director of the Department of Antiquities in Egypt. If it is possible to remove the temple and rebuild it upon the adjacent island exactly as it stands at present, we may rely on his ability to do so; and I ask that his opinion as to the renewal and reconstruction of Philæ temple be obtained before the project for the Assuân dam be altogether rejected.

Were the removal of the temple to be successfully carried out, I cannot myself see that it would be an act of vandalism, which, as I read it, is a term meaning the wanton destruction of interesting relics. In this case there would be no question of wanton destruction. The Government of Egypt would duly weigh on one side, the advantages to the country of the safest and most economical dam which could be constructed north of Wadi Halfa, and on the other, the sentiment which clusters round the site of the present temple and objects to its removal even if it could be done without injury. Finding the advantages to the country to outweigh the sentiment, it would proceed to carry out the work with a religious regard for every detail, and through the agency of the competent staff of the Department of Antiquities.

Removals somewhat similar to that now proposed have been successfully carried out. Mr. Willcocks mentions in his Report having himself, when at Rome, been a witness to the dismantling and rebuilding of the most ancient existing bridge over the Tiber by Italian engineer. Civilized nations in recent times have removed from their original sites and set up in other countries, interesting and valuable monuments. The Elgin marbles taken from the Acropolis and deposited in the British Museum afford an example, and so also do the Luxor obelisk in the Place de la Concorde, and Cleopatra's needle on the Thames embankment. These records of the past have been removed from their historical surroundings, and set up amongst others with which they are not in keeping. We, on the contrary, prompted by a desire to benefit the country, suggest the removal of an ancient building from one site on the Nile to another which is but a few hundred yards distant. We propose re-erecting it exactly as it stands to-day, and on an island in the middle of the great lake which we hope to create, where it would form a beautiful and appropriate object in the landscape.

The Bigeh island is separated from Philæ by some 50 metres of water. The two islands could be connected by a permanent earthen causeway without any inconvenience to the river during the entire progress of the removal of the temple. The proposed site would be about 12 metres above the highest water level in the reservoir. I have had the cubic contents of the sandstone ashlar blocks, which form the temple, carefully measured and find that they amount to 14,300 cubic metres. This measurement permits of an approximate estimate being made of the cost of dismantling and reconstruction.

Earthen dam across the channel between the two islands..............	40,000 at P.E.	4 =	L.E.	2,000
Levelling the platform for the new temple	240,000 at »	5 =	»	12,000
Dismantling, and marking the ashlar blocks before removal..........	14,300 at L.E.	2 =	»	28,600
Transporting and reconstructing on Bigeh islands.................	14,300 at »	10 =	»	143,000
		Total.....	L.E.	185,600
		Contingencies.....	»	14,400
		Grand Total.....	L.E.	200,000

When it is considered that a fair price for new sandstone ashlar masonry is L. E. 2 ½ per cubic metre, I think it will be admitted that the above estimate is an exceedingly liberal one.

I have discussed this question at considerable length, and have done so intentionally. I am quite aware that this proposal will be keenly criticised, and that it will probably be received with disfavour by a large number of persons. At the same time I feel it my duty, when discussing a point of such vital interest

to Egypt as the selection of the best site for a reservoir dam, to bring to the notice and consideration of the Government this possible means of securing what I consider to be the best site, and at the same time avoiding any injury to a beautiful relic of the past. It will rest then with the Government to decide upon the feasibility and advisability of the work. If the decision be unfavourable, the proposed Assuàn site must be struck out of our list; and the dam, if built, must be constructed at Kalabsha, south of Philæ, or at Gebel Sisila If, on the contrary, the decision be in favour of my proposal, we must add L.E. 200,000 to the estimates for the removal and reconstruction of the temple. The revised estimates will then stand thus:—

AREA IRRIGATED	R. L. OF WATER SURFACE IN THE RESERVOIR	CAPACITY OF THE RESERVOIR IN CUBIC METRES	COST
Lower Egypt........................	110.00	1,600,000,000	L.E. 1,300,000
Lower and Middle Egypt...........	114.00	2,550,000,000	» 1,600,000
The whole of Egypt................	118.00	1,700,000,000	» 1,900,000

i Silsila ite. je 18 Report.

We come now to the last of the proposed sites and the one furthest to the north. At a distance of some 70 kilometres downstream of Assuàn, the Nile re-enters the Nubian sandstone by a narrow pass, under 100 metres in width, and 5 metres in depth at low water. This is the Silsila gate of the Nile. It was here that both Linant Pasha and M. de la Motte proposed damming the river, and at first sight it seems to be well suited for the purpose. By its position, it has many advantages over the other projects. It would be nearer to the point at which the water would be utilised: it would be owing to this, that if the perennial irrigation of Upper Egypt were decided upon, the great feeder canals might be taken off at the dam itself, and the supplementary barrage further down the river be economised. The cost of materials and plant brought from Alexandria would be less than in the case of a dam further to the south. The section of the river, with its moderate width and insignificant depth, would be well adapted to the construction of a dam.

Against all these advantages must be set the fact of the rock at Silsila being sandstone instead of granite. It is open to question whether the sandstone has sufficient hardness and solidity to stand the great pressure of water which would be brought upon it when the reservoir was filled. The consistency of the stone is apparently variable, and we have excellent opportunities of studiyng its structure, both in the extensive quarries of the ancient Egyptians, and in the scoured trough of the Nile itself. The quarries on the east bank of the river, in the centre of the hill between the ancient and existing channels of the river, contain excellent stone. These quarries however are well above the present water surface of the

Nile, and the nearer one approaches the water the more inferior appears to be the rock. At these lower levels, the fissures, which are everywhere considerable, are not only present, but there are also horizontal layers of clay and decayed felspar of varying thickness. Everything points to the conclusion that the core of the hill between the two channels is sounder than the bed and banks of the present channel, through which the river cut its way when it abandoned the eastern branch. It would appear that the ancient Egyptians recognised this fact and ran their quarries deep into the heart of the hill and well above the water surface, thus avoiding all inferior rock.

The existence of strata of inferior sandstone and clay compels me to pause before adopting Silsila as a reservoir site. The scouring action of the Nile in flood, as it issues from the undersluices, might be met by a long talus of granite masonry overlying the soft rock in the river's bed; but no protective work on our part could affect the question of the clay strata which underlie the work and which are liable to gradual solution by water under pressure. If one of these strata were dissolved, it would be followed by a collapse of the dam. Under these circumstances I am unable to recommend a higher level for the reservoir than R. L. 101.00^{m}. This level would enable us to store sufficient water for Middle and Lower Egypt, but insufficient for the whole of Egypt. The R. L. of the rocky bed of the river is assumed by Mr. Willcocks as R.L. 74.00^{m}. This would involve a dam 26 metres high, and beyond this, I do not think it would be safe to venture. The borings in the bed of the river have not yet been completed, but they will be ready before the arrival of the technical commission.

So far I have considered the existing waterway of the river. I now turn to the abandoned eastern channel mentioned on page 18 of the Report and page 14 of Appendix VII. This channel, a kilometre and a half in width, was evidently the main stream of the Nile when the river swept over the Komombos plain. Borings have been taken down to R. L. 83.00 through sand and Nile shells without disclosing rock anywhere. The first sight of this old channel inclines one to propose building the dam there and turning the river back into its original course, but we have so far found no trace of rock at a depth sufficiently near the surface to make the project feasible. Further borings are being made in this channel as well as in the actual bed of the river, the results of which, as before remarked, will be submitted to the technical commission. If the dam be constructed in the existing channel of the river, as proposed in the Report, it becomes necessary to close this ancient course of the Nile. Mr. Willcocks proposes doing so by means of an earthen bank 50 metres wide at top, 5 metres above high water level of the reservoir, and let into the rock at either end. It might add to the security of the work to construct two earthen banks, independent of each other, across this right hand channel.

From our calculations, we obtain the following results for the Silsila site : —

AREA IRRIGATED	R. L. OF WATER SURFACE IN RESERVOIR	CAPACITY OF RESERVOIR IN CUBIC METRES	COST
Lower Egypt........................	98.00	1,551,000,000	L. E. 1,450,000
Lower and Middle Egypt............	101.00	2,501,000,000	» 1,650,000

A dam with its crest at R.L. 101ᵐ.00 would place the greater portion of the town of Assuân under a depth of water varying from 3 to 7 metres. The reduced level of the main bazaar is 98 metres; and that of the road in front of the Government offices is 98 metres. The sum allowed for compensation in the estimates of the Silsila reservoir, amounting to L.E. 670,000, has been obtained from figures supplied by Wodehouse Pasha. This sum does not include the cost of removing the recently excavated temple of Komombos, which would be put under 1 ½ metres of water, as the R.L. of its floor lies between 96,2ᵐ and 96.9ᵐ. In this latter respect, there would be no very great difference between the Silsila and Assuân reservoirs. The Komombos temple, though not so well known as Philæ, is still an exceedingly interesting one, and egyptologists would probably insist upon its removal.

The Wadi Rayyan Project. Report page 37. Appendix XI page 19.

I have now arrived at that subject of the Reservoir question which has given birth to much controversy and considerable correspondence. Such authorities on Egyptian irrigation as Sir Colin Scott Moncrieff, Colonel Western, Colonel Ross and Major Brown have recorded their opinion both as to the cost to be incurred and the benefits to be reaped from it. So extensive indeed has been the literature, that the name of the Wadi Rayyân ought to be as well known to the world as that of the lake of Geneva. I shall make no attempt to describe it. With this project the name of Mr. Cope Whitehouse will, as I have already remarked, be always associated. The Wadi is mentioned by Linant Pasha in his work on the Nile, but he never suggested the idea of using it as a storage reservoir. It is to Mr. Cope Whitehouse that the credit of proposing it as a reservoir is due; a proposal which he has for years been urging upon the Egyptian Government.

It is the opinion of all the authorities, whom I have just cited, that the project is a perfectly feasible one, and that the reservoir thus formed could be utilised to supply the wants of Lower Egypt during summer. The question of the cost at which the water would be supplied, and of its being sufficiently low to render the project a remunerative one, has however given rise to differences of opinion. We have to estimate the cost of the works necessary to allow of the reservoir being filled annually between those levels which represent the storage

requiremeuts of Lower Egypt; and we have also to estimate the cost of the works needed to discharge this water at the required rate. With this enquiry is associated the secondary question of the time needed for the reservoir to arrive at that level which would permit it to return its waters to the Nile. The element of time enters into the problem owing to the bottom of the Wadi Rayyan depression being 42 metres below sea level, and the minimum level for discharge being 23 or 24 metres above sea level, making a total depth of water of 65 or 66 metres.

The special questions to be answered with respect to this reservoir are as follows: —

(1) Can these works be made at a cost sufficiently low in comparison with the other projects as to warrant our undertaking them?

(2) Are the advantages of the Wadi Rayyan Reservoir so much greater than those of the Nubian reservoirs, as to justify the adoption of the former regardless of its cost? — I shall discuss the latter question first.

Certainly at first sight the idea of converting this huge depression of 670 square kilometres in extent, into a great lake by means of water taken from the Nile in flood is one which fascinates the imagination. If all the conditions were equally favourable, I should consider this project as theoretically sounder than the damming of the river itself. I say this of course without reference to local and special considerations, or to the expenditure to be incurred as compared to the estimated benefits.

The Wadi Rayyan project has many and great advantages: —

(1) The filling of the reservoir at the time of maximum flood would help to control the floods, although the extent of this control would necessarily depend upon the discharging capacity of the inlet canal from the river into the reservoir.

(2) It would pass back the water into the Nile at the time of lowest supply, and would in no case interfere with the regimen of the river.

(3) There would be no possible element of danger to the country by the sudden bursting of any regulating work.

(4) The water passed into the reservoir would be taken from the Nile when it was purest and most free from any possibility of containing germs injurious to health.

(5) The works would be within easy reach of Cairo and railway communication.

On the other hand it has the following disadvantages: —

(1) The inlet canal must of necessity be made very large in order to fill the reservoir within a reasonable time, and, more particularly so, to enable it to control a high flood and appreciably lower it. This consideration demands that the depression be close to the Nile valley and the intervening country at a favourable level, or there would be a necessity for costly works.

(2) The inlet and outlet canals, if kept separate, would function well, but be twice as costly as a single canal. If one canal had to perform both duties, there probably would be a considerable annual deposit of silt caused by the muddy flood waters flowing into the reservoir by means of a canal which has its slope from the reservoir into the Nile. This deposit would have to be removed annually after the flood in order that the canal might be used to full advantage as a means of outlet.

(3) All the time that the reservoir was emptying, the head of water would be diminishing, and with it, the discharging power of the canal, which would be at a minimum at the end of the season. All this time, the demand for water would be increasing and would attain its maximum at the period when the head of water was lowest.

(4) The water would be taken off the top of the reservoir instead of from the bottom. This would limit its working capacity to the film of water between the surface of the reservoir and the Nile water level. The depth of this film, thus limited, would not be great, and in order to obtain sufficient cubic capacity the necessity of a very large surface area would arise. This again would result in a serious loss by evaporation during the dry Egyptian summer.

(5) An appreciable interval of time must of necessity elapse between the date at which the first filling would begin and the first discharge be obtained. In addition to the great capacity of the depression, we should have to reckon with the few months per annum that water could be withdrawn from the river.

In discussing the projects for reservoirs formed by means of dams, I enumerated on page 17 the objections which could be formulated against them, I now give certain points in which, I think, they would compare favourably with a reservoir created in a depression.

(1) The water issuing from the sluices of a dam would be under complete control, and be more easily regulated than the supply obtained from a reservoir at a distance from the Nile.

(2) The loss from evaporation, in the case of a reservoir formed by a dam, would be comparatively small, owing to the great depth of the water utilised in comparison with the surface area. This is the opposite of what we might expect from a reservoir in a depression.

(3) Issuing from a sluice at the bottom of the dam, every cubic metre of water stored would be utilised.

(4) Immediately on completion, the dam could be regulated, and the full quantity of water required could be stored in 3 months.

In my opinion then, the question resolves itself chiefly into one of cost, as much can be said for and against both systems of Reservoirs.

Lt. Col. Western in 1888 drew up an estimate of what he considered the probable cost of the execution of the Wadi Rayyan project, and indicated the general

lines upon which in his opinion the works should be designed. His estimate, as he has himself always allowed, was only an approximate one. The time given him for its preparation, and the information then at his disposal, sufficed for no more than this. He had no knowledge of the subsoil along the alignmennt of his proposed feeder canal, and the results of the borings ordered by him were not known until he had left Egypt for good. His note on this subject then, was merely a sketch indicating the general lines he had followed in the preparation of this project. It has been upon the lines laid down by him that all subsequent investigations have been carried out.

The consideration and study of this project have occupied the Public Work Department for several years; and if the results we now submit differ from these presented before, the difference is due to the great mass of detail and information which has been collected by us in the interval. Hitherto we have never had at our disposal lines of levels running along the actual alignments of the proposed canals, and the exact heights of the different ridges in the desert between the Wadi and the Nile. We have not before had borings fixing the level at which rock is met with in the desert, or sand in the valley of the Nile.

Mr. Willcocks has prepared two alternative projects and estimates. The first is for separate inlet and outlet canals, and the other for one single canal to serve for both supply and discharge. The main difference between his proposal and that of Col. Western, lies in the alignment of the inlet canal. Mr. Willcocks proposes to carry this channel, after it leaves the Nile valley, straight across the high desert ridge by the shortest possible line. He utilises the depression called by him the Wadi Liernur, and by Mr. Cope Whitehouse the Wadi Lulu, as a means of saving excavation. This depression is about 12 kilometres in length and has its bed some 24 metres below the general level of the desert. Col. Western, on the other hand, took his canal, after it left the Nile valley, along the desert slopes forming the boundary of the Fayoum. The alignment was chosen so as to furnish the most economical section. As before said, Col. Western at the time of writing his note had not the information before him that we now possess. The soil traversed by the canal, although it looks like sound rock on the surface, when bored through, proves to be what Mr. Willcocks accurately describes as " a yellow marl with Epsom salts, and finally a bitter plastic clay of a black colour overlying the Parisian limestone". These marls and clays, on immersion in water, speedily dissolve, and possess no trace of a power to resist disintegration in the presence of water.

The existence of the yellow and black clays overlying the limestone throughout the whole ridge traversed by the supply canal is confirmed by the borings. I am of opinion that the canal may be taken through them in excavation but not in embankment; a bank formed of such material and brought in contact with water would speedily dissolve. Under these conditions, I cannot

but conclude that any canal taken along the inner slopes of the Fayoum, if only in partial embankment, would endanger the safety of the province. The same canal kept completely in soil would speedily waterlog and render salt, by its dangerous proximity, a considerable strip of the low lying cultivated land. It is for these reasons that I prefer Mr. Willcocks' proposal to carry the canal straight across the ridge where it will be in deep digging and well removed from the cultivated land. This view is shared by Col. Ross and Major Brown. The straightest line is necessarily the shortest, and its adoption results in a minimum loss of head between the reservoir and the Nile at the time of discharge. This point is one of supreme importance when the water in the reservoir approaches its lowest levels.

Of the two alignments in the desert marked on the plan (Plate XV), I prefer the one to the south called the Bahr Bilama line, for, though it crosses a larger stretch of the high desert plateau, it is not so costly as the Abu Hamed line to the north, and also traverses a much shorter distance of the salty clay soils than the other.

The project for separate inlet and outlet canals is described in paras 77, 78 and 79 of the Report, and the project for a single combined canal in para. 80 of the Report, and on page 19 of Appendix XI. I have already recorded my opinion that separate canals are preferable to one canal performing both functions, but I am compelled to decide in favour of a single canal for the Wadi Rayyan. The first cost of the separate canals is so great as to make this project compare unfavourably with the Nubian dams. The economy realised by having a single canal amounts to L.E. 597,000 (see page 34 of the Report).

The canal proposed by Mr. Wilicocks has a length of 25 kilometres in the Nile valley and 30 kilometres in the desert. At the junction of the desert and Nile valley is the Bahr Yusuf, which it is proposed to make the feeder canal when the reservoir is working. The line in the desert acts as both feeding and discharging canal to the Reservoir. Mr. Willcocks proposes to construct the inlet canal along this line, and dig it with its head at R.L. 22.25, and slope of $\frac{1}{20,000}$ into the Wadi Rayyan. It vill be used as an inlet canal during the period of first filling the reservoir, after which it will be deepened on a slope of $\frac{1}{10.000}$ backwards into the Nile and act as an outlet canal only.

At the 4th kilometre in the desert, the canal is well within rock, and Mr. Willcocks allows a drop of 4 metres for the sake of economising the section of the rock cutting. His bed width is 40 metres in clay, and 25 metres in the rock, where the increased depth allows of this contraction without reducing the discharge.

Borings were taken in the Nile valley at a distance of about 4 kilometres apart, and in the desert at every second kilometre. In the Nile valley, sand was found underlying the clay at levels varying from R.L. 19.00^{m} near the river to R.L. 21,00 at the edge of the desert. Mr. Willcocks insists that the bed of

the canal should not descend into the sand but should be kept within the clay, and has designed his canal upon this principle. He bases his reasons upon the extreme difficulty of the subsequent keeping open and clearing of the channel; and he also anticipates heavy slips in the side slopes during the time that the canal will be closed and the reservoir not working. I admit to a certain extent the validity of his arguments, although I consider that the question resolves itself into one of cost.

I approve of Mr. Willcocks' proposed sections of channel given in para. 77 of the Report. The deepest cutting in the desert will be 39 metres. Although the ridge is high and the cost of traversing it great, still there is a compensating economy in carrying the line through the depression called by M. Cope Whitehouse, the Wadi Lulu.

Mr. Willcocks has worked out his estimates very carefully, and has, I think, been actuated by a wish to give every advantage possible to this projeet. He has in consequence reduced his rates of earthwork to a point so low that I am doubtful whether the work could be actually executed at such a cheap rate. He allows:

For earthwork in the Nile valley....	4	P.E.	per	metre	cube.
» the bitter clays and marls	5	»	»	»	»
» Loose sand at the surface.......	2	»	»	»	»
» Rock cutting.................	8	»	»	»	»

The rates for ordinary earthwork and for excavation in the surface sand are good ones, but I doubt whether 5 P.E. per metre cube is sufficiently high for the bitter clays with their great depth and consequent difficulty of removal.

His rate again for rock is as low as it is possible to go, when we consider the depth of excavation and the expense of blasting. The cubes of stuff to be removed are sufficiently high to have an effect on reducing the rates, but making all allowances for this, the rates as they stand are very low, and although I shall not alter them, I think it only right to record that in my opinion they have been run down to the extreme limit consistent with the compilation of an accurato estimate.

On page 31 of the report, the daily evaporation in summer is taken at 8 millimetres per day, or 25 centimetres per month. This estimate is based upon experiments made by both Mr. Willcocks and Major Brown on the Qurun lake in the Fayûm. Professor G. Schweinfurth, the eminent traveller and scientist, in a note (Appendix XIII) which he has kindly written in reply to my enquiry as to tbe possibility of salt eventually existing in the water of the Rayyan reservoir, estimates the loss from evaporation as somewhat less than that given by Mr. Willcocks. He however considers, and gives his reasons for doing so, that the loss by percolation and infiltration through the desert will be very considerable; I think it safer then to accept Mr. Willcocks' figures as they include no allowance for possible loss from percolation.

The cost of the Wadi Rayyan single canal project, as designed by Mr. Willcocks, is L.E. 1,990,000 according to his own figures in the Report, or L.E. 2,013,400 according to Mr. Marshall Hewat's figures in Appendix X. His calculations go to show that, at the commencement of the month of June, the water level in the reservoir would stand at R. L. 25.60^m and fall steadily till the end of July when it would reach R. L. 24.00^m, and the reservoir would cease to function. During these two months, the canal would be discharging 11,000,000 metres cube per diem. It has however been shown that both Mr. Foster and Mr. Willcocks require for the maize cultivation of Lower Egypt a far higher discharge than this in July. The former states his mean requirements at 24,000,000 metres cube per diem, and the latter at 26,000,000 metres cube per diem.

The proposed canal will not give half the above discharge and will not consequently assure to Lower Egypt its required supply. Now although Mr. Willcocks has endeavoured to reduce the cost of the project as much as possible, I cannot see the use of carrying out this work at all unless the canal be made of sufficient capacity to supply the whole of Lower Egypt during the months of June and July. Either then we must keep the bed within the clay and widen it considerably, or we must deepen and descend into the sand. The latter gives the more economical section and should therefore be adopted, but either alternative increases the cost of the work. Mr. Willcocks is himself aware of the insufficiency of his canal and, on page 34 of his report, gives an estimate for deepening the bed and making the channel capable of discharging 20,000,000 cubic metres per diem or 230 metres cube per second, at an additional cost of L.E. 253,000; but he considers this deep canal as impossible to maintain. Major Brown in his notes criticises this portion of M. Willcocks' project and calculates that the canal bed, in order to discharge the necessary 300 metres cube per second, must be widened from 40 metres to 60 metres, and the depth increased from 4 metres to 6 metres, while the slope across the Nile valley must be changed from $\frac{1}{10,000}$ to $\frac{1}{25,000}$. He estimates the additional cost of these changes at L.E. 728,420. The addition of this sum to Mr. Willcocks' figure of L.E. 1,990,000 brings the total estimate up to L.E. 2,718,420. Major Brown has based his discharges upon the supposition that the July requirements of Lower Egypt will not exceed 510 metres cube per second. Mr. Foster however considers that a gradually increasing discharge is absolutely necessary during July, and calculates the maximum at the end of the month at 860 metres cube per second. As all my calculations in this note concerning Lower Egypt have been based upon Mr. Foster's figures, I must then accept this discharge as being that required for Lower Egypt, and proceed to show how the Wadi Rayyan project must be carried out in order to meet these requirements.

The mean low water level of the Nile, at the point where the canal would join it, is R.L. 21.50^m, which by table I of appendix III represents a discharge of

410 metres cube per second in the Nile. A discharge of 860 metres cube per second is represented by 1 metre in the table, and by a R.L. of 22.50^m. On page 29 of the report, it is shown that the full supply level in the reservoir must be fixed at R.L. 27.00^m. It is further assumed in all the calculations that there will be a drop of 40 centimetres between the reservoir and the head of the outlet canal at the Bahr Yusuf. Working back on these figures, it can be proved, that, with a slope of $\frac{1}{25,000}$, the lowest level at which water can be drawn from the basin will be R.L. 23.90. Before this project can be thoroughly understood, the requirements of irrigation and the discharge of the Nile must be considered at shorter intervals of time than the 15 days intervals allowed for in the dam reservoirs. The requirements of irrigation are gradually increasing as the month of July advances, the discharge of the Nile itself is increasing independent of any water from the reservoir and is being augmented by the supply from the Wadi Rayyan; and, all this time, the level of water in the reservoir is falling. The problem is a most complicated one, for, unlike the Nubian dams which can discharge by sluices at the bottom and are independent of a slight rise in the Nile, the Wadi Rayyan is an overflow basin and its power of discharge depends entirely on the difference of level between its water surface and that of the Nile.

As already stated, Mr. Foster, on page 7 of appendix XII, gives it as his opinion that the requirements of the expanded area during July would rise from 36 millions to 72 millions of metres cube per diem. He expressly states moreover that the demand would increase gradually throughout the month, and he fixes the mean at 56 millions of metres cube per diem. Working then upon Mr. Foster's calculations of discharge, I have requested Mr. Willcocks to reconsider certain of his figures and to tabulate the results; this he does as follows: —

DATE 1	DISCHARGE REQUIRED IN MILLIONS OF METRES CUBE PER DAY FOR IRRIGATION OF LOWER EGYPT. 2	DISCHARGE AVAILABLE IN RIVER, IN MILLIONS OF METRES CUBE PER DAY. 3	BALANCE REQUIRED, IN MILLIONS OF METRES CUBE PER DAY. 4	FIGURES OF COLUMN 4 IN METRES CUBE PER SECOND. 5	R. L. OF THE WATER SURFACE OF THE NILE AT THE TAIL OF THE OUTLET CANAL. 6
May 1st to 31st	30	21	9	100	21.3
June 1st to 30th	36	19	17	200	21.6
July 5th	42	18	24	280	21.7
» 10th..........	48	19	29	340	21.9
» 15th..........	54	25	29	340	22.1
» 20th..........	60	50	10	110	22.3
» 25th..........	66	60	6	70	22.4
» 31st..........	72	120	..	..	22.6

Column 2, gives Mr. Foster's increasing discharges at five day periods.

Column 3, gives the discharge available in the River calculated from the table on page 8 of the Report.

Column 4, gives the deficiency required to be supplied by the Reservoir.

Column 6, gives the level to which the River would rise in consequence of its increased discharge, according to Table I of appendix III.

Now turning to para. 76 of the report, the figures given there may be thus modified: —

					AT THE HEAD OF THE OUTLET CANAL
On the	1st April	the R. L. of the lake will be	27.00.	and the R. L.	26.60
»	1st May	» »	26.75,	»	26.35
»	1st June	» »	26.00,	»	25.60
»	1st July	» »	24.95,	»	24.55
»	15th July	» »	24.20,	»	23.80
»	25th July	» »	24.05,	»	23.65

In other words, the film of water between R.L. 27.00 and R.L. 24.00 in the Reservoir will suffice; and it has been shown, on page 30 of the Report, that this film can be annually renewed by the (1) Bahr Yusuf during winter with the aid of the Assyût Barrage across the Nile. The water supplied will meet the requirements of Lower Egypt, but will allow nothing for either of the Damietta or Rosetta branches.

The maximum discharge required from the Wadi Rayyan is 340 metres cube per diem on the 15th July with the water level at the head of the outlet canal at R. L. $23^{m},80$, and the Nile at R. L. $22^{m},10$. There is therefore an available slope in the Nile of $\frac{1.7}{25,000}$ or $\frac{1}{15,000}$. If we allow a depth of water of 5 metres at this stage of the discharge, the R. L. of the bed becomes $18^{m}.80$. The bed width of the canal may be taken at 61 metres, as this gives a sectional area of 340 square metres to the channel and a mean velocity of 1 metre per second, which may be considered as a safe maximum. Major Brown allows for a canal with a 60 metres bed width, R. L. of bed $19^{m},00$, and slope of $\frac{1}{25,000}$. This canal is so close to the one now calculated that I accept his figure of L. E. 2,718,420 as the cost of the Wadi Rayyan canal if it is to meet the requirements of Lower Egypt.

Major Brown points out that, if the Bahr Yusuf be used, as we propose it shall be, for the purpose of filling the Reservoir, it can no longer be used as the great drain of Middle Egypt, and that consequently a parallel drain must be dug in the lowest part of the Nile valley; this will, of course, materially add to the cost of the project as a whole.

If then we calculate the water needed per annum from the Wadi Rayyan Reservoir according to the table just given, we shall find that the total requirements from this Basin amount to 1,280,000,000 metres cube per annum as against 1,551,000,000 from one of the dam reservoirs. When however it is remembered that the Wadi Rayyan is 800 kilometres nearer

(1) Without accepting the fact that the depth of the film of water capable of being utilised lies only between R.L. 24.00^{m} and R.L. 27.00^{m}, we cannot use the Bahr Yusuf as a means of filling the Reservoir, unless we suppress the Middle Egypt basin. Major Brown, on page 19 of his note, shows that, in order to fill the Rayyan Reservoir between R.L. 23.00^{m} and R.L. 27.00^{m}, the Yusufi canal must function from September to February. In September and October this canal is required for the filling of the Basins. Unless then these are suppressed, and their suppression would necessitate the construction of a dam reservoir to the south, we must either consider the Yusufi as only a partial means of filling the Reservoir, or accept that the film of water between R.L. 24.00^{m} and R.L. 27.00^{m} will alone be drawn off.

to the heads of the Lower Egypt canals than one of the Nubian dams, it will be evident that the difference between the figures representing the requirements has reference to the volume by which the water in the River, on this reach of 800 kilometres, would have to be augmented by the discharge from a dam reservoir, to allow of the increased supply reaching our Lower Egypt canals. In the case of a Nubian reservoir as compared to the Wadi Rayyan reservoir, there would always be this waste; for since the Nile flood travels at double the velocity of the ordinary summer supply, that portion of the water which left the Reservoir during the last days of supply would be overtaken and overlapped by the flood and be lost to summer irrigation. This waste would be directly proportional to the distances between the Reservoirs and the heads of the canals to be supplied, and could in no case be avoided owing to our inability to foretell the date of the arrival of the flood. We should have to discharge the water from the Reservoir just as though no flood were coming, and allow half the supply between the dam and the canal heads to be overlapped by the flood and practically wasted.

A question, such as that of the rate at which the rising flood water would overtake and overlap that in the river, is an excendingly difficult one, and one almost impossible to theorise upon with any degree of accuracy. At the same time, I have tried in the foregoing paragraph to attempt this, as it is only upon the supposition that the water issuing from the Wadi Rayyan basin (at a rate in July beyond our power to increase), would be augmented and assisted by the flood within the critical period of demand in Lower Egypt, that we can accept the Wadi Rayyan project as a possible one at all. There will always then be an element of doubt concerning its success; for unless the flood water overlaps the Rayyan water at the necessary rate and at the exact period required, the discharge from the Rayyan reservoir cannot be increased beyond the natural capacity of the canal, and there will undoubtedly be a failure in the Lower Egypt supply.

Since the lowest point of the Wadi Rayyan is at R.L. —42.00^{m}, and the lowest level at which water can be utilised is R. L. + 25.00^{m}, the entire void of the Depression to a vertical height of 66 metres has to be filled before it can be used at all. The reservoir below this level has a capacity of 16,806,000,000 cubic metres (see table I of Appendix X) and would take time to fill. Mr. Willcocks, on page 30 of his report, works out the probable time that it would take to fill the Reservoir. In this calculation, allowance has been made for years of low flood when the level reached at Cairo would not have exceed 20 $^{1}/_{2}$ pics and the Nile supply would only have been sufficient to meet the necessary demands of irrigation. In such years, which have amounted to 6 in the last 20, no water could have been drawn off for the Reservoir. Similar years must then be considered as lost as far as the supply to be obtained in flood is concerned. Mr. Willcocks has taken as an example the period beginning with the year 1873, and has calculated

that it would have taken 7 years for the reservoir to have been raised to the full level of R.L. 27.00^{m}. Col. Western, working upon somewhat similar lines estimated the time at 8 flood seasons. As the previous calculations were made with a 40 metre wide canal, while I have allowed for a 61 metre wide canal, the time of filling of the Reservoir would probably be decreased, but there would probably be an increase in the time of construction. I do not then think that we should be able to reduce the total below the calculations given by Col. Western and Mr. Willcocks. The amounts of evaporation and percolation are doubtful quantities, upon which there is some difference of opinion, and consequently the foregoing calculations can only be considered as approximate. We may however safely assume, I think, that the reservoir could not be filled in less than 7 years. If we allow 3 years for construction, we arrive at 10 years as the interval which would elapse between the date of the turning of the first sod of the canal and that on which water could be drawn from the Reservoir for the purposes of irrigation.

Col. Ross, Major Brown and Mr. Foster, all discuss the possibility of using the Wadi Rayyan as a flood escape, but all do so unfavourably. Col. Ross considers that no discharge under 60,000,000 metres cube per diem by means of the inlet canal and 40,000,000 metres cube per diem by means of the Bahr Yusif would be of any avail. This discharge is two fold the capacity of the estimated canal. Major Brown argues that the suppression of the basins would not materially affect the maximum rise of the flood, and that consequently it would be useless to go to so great an expense for so small a return. Mr. Foster states his opinion that nothing under a discharge of 185,000,000 metres cube per diem would sufficiently reduce a dangerous flood in Lower Egypt.

I conclude by saying that the Wadi Rayyan Reservoir project is a feasible one, although even under the most favourable conditions the element of doubt to which I have already called attention must always exist. As compared with some of the Nubian reservoirs, it is a very costly work. It could at first be filled by a canal from the Nile, and afterwards maintained at a working level by means of the Bahr Yusuf through the agency of a Barrage at Assyût. At a cost of not less than L.E. 2,727,420, it would be capable of assuring the water supply of Lower Egypt. It would take not less than 10 years from the date of commencing work before use could be made of it but, at the same time, there would never be any question of danger to the country connected with it. Were it not for the doubts expressed above, its excessive cost, and the fact that it would only serve Lower Egypt, I should not have hesitated to recommend its execution to Government. As matters stand however, certain of the Nubian reservoirs are considerably, less costly and capable of relieving a far larger area of country. I am compelled then to abandon the Wadi Reyyan project in their favour.

We have tried by every means in our power to arrive at a just estimate of the cost of this work, even I fear going to the length of under-estimating the sum required. I would recommend that Mr. Cope Whitehouse be given every facility of stating his own views and opinion upon this project before the technical commission. He has associated himself for so long a time and with such earnestness with the cause of the Wadi Rayyân that he is, I think, fairly entitled to this concession. More than this; he shall, if he wishes it, have free access to the information by means of which we have arrived at our estimates.

Working with the figures that I have given in the preceeding page of this note, I can now tabulate the comparative cost and financial results of all the different schemes.

Table of cost and financial results of the different reservoir schemes.

NAME OF PROJECT	R.L.	COST	COUNTRY SERVED	DIRECT ANNUAL RETURN TO THE STATE	INCREASED VALUE OF LAND IN EGYPT	INCREASE TO ANNUAL PRODUCE	INCREASE TO ANNUAL RENT
	METRES	L.E.		L.E.	L.E.	L.E.	L.E.
Kalabsha dam.	118.00	1,600,000	Middle and Lower Egypt	850,000	23,148,840	7,975,600	3,946,900
» » .	114.00	1,250,000	Lower Egypt...........	278,000	not allowed for.	3,290,000	1,600.000
Philæ dam....	118.00	2,100,000	Whole of Egypt........	850,000	46,198,180	12,612,900	5,390,900
» »	114.00	1,750,000	Middle and Lower Egypt	850,000	23,148,840	7,975,600	3,946,900
» »	110.00	1,500,000	Lower Egypt...........	278,000	not allowed for.	3,290,000	1,600,000
Assuân dam...	118.00	1,900,000	Whole of Egypt........	850,000	46,198,180	12,612,900	5,390,000
» » ...	114.00	1,600,000	Middle and Lower Egypt	850,000	23,148,840	7,975,600	3,946,900
» » ...	110.00	1,300,000	Lower Egypt...........	278,000	not allowed for.	3,290,000	1,600,000
Silsila dam....	101.00	1,650,000	Middle and Lower Egypt	850,000	23,148,840	7,975.600	3,946,900
» »	89.00	1,450,000	Lower Egypt...........	278,000	not allowed for.	3,290,000	1,600,000
Wadi Rayyân.	27.00	2,727,000	Lower Egypt...........	278,000	not allowed for.	3,290,000	1,600.000

When I discussed the probable financial results earlier in this note, I remarked that the figures were startling. I can only repeat what I then said, and add that, if we even deducted a large margin of profits, we should still have a sufficiently large balance to warrant an expenditure in excess of that of the most costly of our projects.

Effect on the Nile floods of a suppression of the basins. Report page 37. Appendix XI page 13. Appendix III.

I shall defer summing up and formulating my recommendation to Government as to which of the above projects is, in my opinion, the most worthy of adoption, until I have considered the effects of the introduction of reservoir water into the country. The construction of reservoirs for providing Egypt with perennial irrigation will be accompanied by a suppression of the existing basin irrigation of Upper Egypt, and by a modification of the existing canalisation. I take up the suppression of the basins first.

Colonel Ross in his note on the subject ("Nile Reservoirs" 1891 pages 55 to 59) discusses this question at great length. He allows 200,000,000 cubic metres per diem as the quantity of water drawn off by the basin canals at the time of filling. He calculates that the extension of perennial irrigation to the basin tracts would reduce the volume required for irrigation by 150,000,000 cubic metres per diem and that this quantity would help to swell the flood. He cites as an example his flood observations in 1889 with the Assuân gauge reading 17 p. 1 k. and the Cairo gauge 22 p. 4 k., at a time that the basin canals were discharging 200 millions of cubic metres per diem. If their discharge had been reduced by 150 millions per day, the Cairo gauge would have risen to 23 p. 9 k.; a difference of 65 centimetres.

Again Colonel Ross contends that the suppression of the basins would render drainage impossible, even during a moderately high flood. The chains of basins are drained at present into the Nile by means of escapes, and are so arranged that the tail basins shall always stand from 25 to 30 centimetres above the maximum level of the Nile. With the basins under cultivation, the water in the river would stand at least 2 metres in high flood, and 1 metre in low flood above the level of the ground in the basins. Drainage would consequently be quite impossible, and the regulation of the flow in the deep summer canals, when demand slackened, would be extremely difficult, not to say impossible.

A third danger pointed out by him is the possible encroachment of the desert sand upon the basin lands if the basins were suppressed. He admits that this may be fanciful, but considers it to be within the bounds of possibility, and gives instances to prove his theory.

Finally he proposes to retain a chain of basins between Farshut and Koshesha, amounting to 182,000 feddans in all. These basins are to act as receptacles for the drainage of the tracts put under perennial cultivation, and are to be so arranged that the terminal basin of each series shall have its water level a little above the maximum flood level of the river and be thus capable of discharging into it.

Sir Colin Scott-Moncrieff in his review endorses Col. Ross' opinion.

Mr. Willcocks, in pages 37 to 43 of his report, has considered this question in very great detail, and the figures on which he bases his arguments are to be found in Appendix III. He has taken a continuous series of discharges throughout 1892 and 1893, and referred every gauge on the Nile to the uniform standard of mean low water level (in which I agree with him). By applying his observed discharges to these newly found gauges, and making modifications to suit the recorded maximum and minimum floods of the past 20 years, he has drawn on plate XXVII a discharge diagram for the Nile. By means of cross and longitudinal sections of the Nile between Assuân and Cairo, he has calculated the contents of the trough of the Nile, and studied the part it plays in the regulation of the flood. Finally he has endeavoured to estimate the

effects of evaporation and absorption by observations on the floods of 1892 and 1893.

He estimates that the consumption of water in flood between Assuân and Cairo, with perennial irrigation, will be as follows: —

Perennial irrigation......	700	metres	cube	per second.
Evaporation............	120	»	»	»
Absorption.............	200	»	»	»
TOTAL. .	1,020	»	»	»

The balance of the flood, modified by the amount of water expended in filling the trough of the Nile, will pass Cairo and distribute itself between the Rosetta and Damietta branches. His conclusions are as follows: —

The suppression of the basins would result in an advance of the date on which the maximum flood level would be reached at Cairo, and a corresponding advance in the date that the flood would begin to fall.

A high flood would be 15 days earlier than under present conditions and an ordinary flood 25 days earlier. He further arrives at the result that, with perennial irrigation, the maximum gauge at Cairo, as referred to the maximum gauge at Assuan, would not rise above the level that it used to attain with basin irrigation before the inauguration of Col. Ross' Sharakî works. These works have so changed the regimen of the Nile in flood, and consequently the maximum at the Cairo gauge, that the Assuân gauge is the only one with which comparisons can be made. For further study of this complicated question, I refer any one to para. 93 of the report and table VI of Appendix III.

In high floods, he considers that the gauges would not be increased at all.

In order to arrange for the drainage of the country put under perennial irrigation, he adopts Major Brown's proposal to utilise the Sohagia and Yusufi canals as main drainage lines; he recommends their prolongation and final termination in the Rosetta branch downstream of the Barrage. This main drain would carry 300 cubic metres per second and relieve the Damietta branch of its share of this discharge.

Major Brown has also studied the question of the suppression of the basins very closely and recorded his opinion in his note (Appendix XI).

His observations accord in great measure with those of Mr. Willcocks. He does not consider that the suppression of the basins would produce a very great effect upon the flood level at Cairo. He points out that without basins, the rise and fall of the river at Cairo must more closely follow that at Assuân, and that the more quickly the Cairo gauge will rise the more quickly will it fall. The infiltration through the soil in flood time, which is active now in October an November, will be active in August and September, and will be more easily mastered by evaporation owing to the greater powers of the sun. He further states that the regulating heads of the basin canals are to-day partly

closed when the flood rises above 16 $\frac{1}{2}$ pics at Assuân and that consequently, even under the present system, the effect of closing the basin canals is produced during high floods.

Major Brown gives tables to show the fall in the level of the river, produced by the opening of the basin canals in the different reaches of the river south of Kushesha, and he argues that the suppression of the basins would result in an increased height of flood between the 15th August and the 15th September, and in a corresponding decrease aftewards. As the final result of his calculations. he gives his opinion that the flood level, owing to the suppression of the basins, would rise 50 centimetres south of Assyût, and a further 30 centimetres north of Assyût, making a total rise of 80 centimetres at Cairo. This rise according to him would be a rise in point of time, and would not affect the maximum gauge of the year, whose advent would be advanced by three weeks or a month.

He does not think that the preservation of 182,000 feddans of basins out of a total area of 1,030,165 feddans, as proposed by Col. Ross, would have any material effect upon reducing the height reached by the flood at Cairo.

At the same time, he considers the drainage question as the most important argument in favour of the retention of a limited area of basins in each chain. He suggests, as regards Middle Egypt, the retention of a terminal basin at the extreme north end of the chain, unless indeed the alternative system of embanked drains, as used in Italy, be substituted. The conclusion to which he finally arrives is, that the partial or complete suppression of the basins in Upper Egypt should not be attempted at present; the experiment should be confined to Middle Egypt north of Assyût, and we should watch its effect upon that portion of the Nile valley before we extend it further south.

It will be evident from the foregoing that there is, to a certain extent, a difference of opinion as to the result of a complete suppression of the basin system of Upper Egypt. That the maximum flood at Cairo will be reached earlier than what it does at present, and the river will begin to fall at an earlier date, is accepted by all. As regards the actual height which the maximum will attain, there is a difference of opinion between Col. Ross on one side, and Major Brown and Mr. Willcocks' on the other. All are agreed that without basins there will be a difficulty about the drainage of the lands under perennial irrigation, although Mr. Willcocks' suggestion that Major Brown's main drain be continued to the Rosetta branch is a possible solution.

Taking everything into consideration, we cannot say that our calculations have been based upon facts about which we possess absolute certainty. Mr. Willcocks' studies upon this point, minute and careful as they may have been, have not covered more than two years, which is a short interval of time for a subject so difficult as the regimen of a great river like the Nile. An error of judgment on our part might expose the country to great risk if not to danger, and I am therefore of opinion that we should, for the present, postpone all question

of the suppression of the Upper Egypt basins south of Assyût We should limit our proposals to the construction of a dam large enough for the wants of Middle and Lower Egypt alone; and I go even beyond this, and, accepting Col. Ross's proposition (agreed to in a certain measure by Major Brown) I lay it down as a rule to be followed in all our calculations, that a certain area of basin should be retained to act as a drainage receptacle for the newly cultivated lands.

The exact extent of this retained area can be afterwards decided upon when we are studying the detailed projects for the utilisation of the water from the reservoir. I do not suggest that this retention should necessarily be permanent, but that, for a certain number of years after the completion of the reservoir, we should study the actual effect of the partial suppression of the Middle Egypt basins. It is true that this method of working will, at any rate for a time, deprive a certain area of land of the benefits of perennial irrigation. In consequence of this, the figures already given as representing the increased rental, produce and value of land, will have to be reduced by a sum proportional to the area of basin retained, but there will be this compensation that after some years of study we shall be in a better position to predict the exact result of a change so radical as the conversion of basin into perennial irrigation. In my opinion, certainty on this point will constitute an advantage which will far outweigh the temporary inconvenience of a certain amount of delay in the realisation of the benefits of an improved supply of water to a limited area of land.

Works necessary in Middle and Lower Egypt in order to permit of the water from the reservoirs being utilised. Appendices XI and XII.

It is evident that any considerable addition to our water supply in summer will necessitate certain changes in our existing canal system, to enable us to make use of this extra supply. It is also evident that these changes should, as far as possible, be carried out simultaneously with the construction of the Reservoir. In this way only, will it be possible for the increased water supply to be utilised as soon as it is available, and the country be able to obtain as quick a return as possible for the capital expended.

I have already stated in this note that, in my opinion, we should for the present omit those Reservoir projects which concern the irrigation of Upper Egypt. With respect to the others, I consider that, if a dam be built at all, it should be built high enough to supply the wants of Middle and Lower Egypt combined. The difference between the cost of a work sufficient for both, and the cost of a work sufficient for Lower Egypt alone, is comparatively small, and out of all proportion to the benefits to be realised by the admission of Middle Egypt to summer cultivation. The expense of getting in the foundation is the main source of expenditure in a work of this kind and is practically the same for the two projects; the superstructure, which experiences the greatest change, is relatively inexpensive. As far as the reservoir projects are concerned, we are therefore in my opinion limited to the consideration of those which are capable of supplying Middle and Lower Egypt together.

The Wadi Rayyan project will, it is true, only benefit Lower Egypt, but as it stands apart from the other schemes, and as moreover the merits of the two rival systems are to be studied by the Technical Commission, I shall, for the purposes of comparison, examine the question of the additional works contingent on the adoption of this project also.

A Reservoir in the Nile valley will necessitate the following original constructions and remodellings: —

I. — *Middle Egypt.*

(*a*) A Barrage in the Nile at Assyût.

(*b*) Alterations in the levels and sections of the main supply canals to enable them to pass the increased volume in summer.

(*c*) The construction of sundry branch canals for the better distribution of the supply.

(*d*) The completion and remodelling of the drainage system.

II. — *Lower Egypt.*

(*e*) The remodelling of a great portion of the existing system of canals, so that, with the Barrage held to R.L. 14.00^m, they might be capable of discharging the extra supply.

(*f*) The construction of branch canals for the distribution of the supply, and for the irrigation of the area at present uncultivated, but which will be reclaimed under the new conditions.

(*g*) The completion of the drainage system.

The Wadi Rayyan project will necessitate all the works enumerated above under the head of Lower Egypt, and in addition to them the construction of the Assyût Barrage, whose existence has been assumed in all the calculations connected with the filling of that reservoir.

Major Brown and Mr. Foster work out in considerable detail the works necessary in their respective districts. Naturally their estimates are only approximative, but their knowledge of the country and of the future requirements of the irrigation system enables them to foretell closely the expenditure which will be entailed. I shall give a brief epitome of their notes which can be referred to for details in appendices XI and XII.

The Barrage at Assyût.

We are united in considering that this work is a necessity for the better irrigation of Middle Egypt and the Fayum, and should be constructed independently of the result of any decision about the Reservoir. It would be placed downstream of the present head of the Ibrahimia canal.

By raising the level of the water in summer, it would not only control the discharge of the canal, but enable us to make a great economy in our annual dredging cubes, if not to dispense with them altogether.

Supposing that no Reservoir project were carried out, this work would be used not for the purpose of increasing the water supply of the Ibrahimia canal except perhaps in exceptional cases, but solely for the purpose of raising the surface of the water and enabling it to be delivered at a higher level than at present. In the case of the Wadi Rayyan project being decided upon, this Barrage would be equally necessary; for the Bahr Yusuf, which itself is fed by the Ibrahimia, would be the feeder canal of the Reservoir, and its ability to perform its functions would depend upon the supply being maintained, during the falling flood, in the Ibrahimia canal. Mr. Willcocks has designed this Barrage, and his estimate of the cost of the work, including a new head for the Ibrahimia canal, amounts to L.E. 700,000, if designed for irrigation purposes only. A sum of L.E. 100,000 should be added to these figures if the Barrage is to be used for filling the Wadi Rayyan.

Major Brown shows on the small map accompanying his report, the general arrangements of the canals and drains that he considers indispensable to the successful working of the proposed new system of irrigation in Middle Egypt. He also estimates for widening the Ibrahimia canal so as to render it capable of carrying the increased discharge. Lastly he estimates for a new main drain which would be a prolongation of the Sohagia and Yusufi canals, and which, passing through the province of Giseh, would discharge the drainage waters of Upper and Middle Egypt into the Rosetta branch of the Nile at a point north of the Barrage. His estimate is a follows: —

Branch canals and drains	L. E.	308,500
Enlarging Ibrahimia canal	»	57,000
Main drain	»	600,000
TOTAL	L. E.	965,500

As regards the first two items, I confine myself to saying that the works would be spread over a series of years and that a portion of them might possibly be carried out under the ordinary Irrigation Budget grant; I do not propose to reduce the figures. Major Brown has great knowledge of the requirements of the provinces under his charge, and has studied the question most carefully. As regards the sum allowed for main drainage, I am not prepared to acknowledge the necessity of spending such a large amount at present. In the first place, I am proposing to leave Upper Egypt out of the question as far as the present project is concerned; and even were its basins to be suppressed, I think the Sohagia, which would act as the main drain, might be made to discharge into the river at a point south of Assyût. We should then only have to consider the capacity of a channel large enough to drain the country north of Assyût. This would materially reduce the required section of the drain, and I estimate that a channel of 40 metres bed width, running 4 metres deep, down the natural

depression at the foot of the deserts would meet the necessities of the case. Such a work could be constructed at a cost of L.E. 200,000. In the second place, it must be remembered that if, as I propose, a certain area of basin is for the present to be retained as a drainage receptacle, there will be no immediate necessity for the execution of this work. At the same time, as there is no intention to make this retention permanent, it follows that the necessity for the drain will arise on the suppression of the basin. This work is moreover undoubtedly contingent on the construction of a reservoir, and I therefore include it in the estimate of the total cost. Major Browns' estimate for Middle Egypt will then become : —

Branch canals and drains......................	L. E.	308,500
Widening Ibrahimia canal	»	57,000
Main drainage...............................	»	200,000
TOTAL.....	L. E.	565,000

Or say L. E. 566,000

Lower Egypt.

In considering the works necessitated by the Reservoir project in Lower Egypt, we have a more difficult problem before us. We have to decide whether it will be more advantageous to deepen and widen the great main supply channels taking off from the upstream side of the Barrage, in order to enable them to carry the increased supply; or whether it will be preferable to construct supplementary Barrages in the two branches of the Nile and, with their aid, feed the canals which irrigate the lands in the north.

Mr. Foster, in his note (Appendix XII), has carefully studied this question and gives it as his opinion that the construction of a Barrage on the Damietta branch, a little to the North of Zifta and 95 kilometres downstream of the existing Barrage, would be the most effective and economical method of working, as far as the Damietta branch was concerned. I entirely agree with him. The work of widening and deepening the great canals which run through the most highly cultivated portions of Lower Egypt would entail great difficulties, and be very costly. We should have to deepen them by some two metres and this would be no easy task in the slime that is found in the beds of all canals in Egypt. The widening entailed by the deepening would necessitate our taking up valuable land for which heavy compensation would have to be paid, as well as for the engines and sakias which would have to be removed. We should moreover have to alter or enlarge all our locks and regulators, a work both costly and dangerous, especially when it is considered that the floors of most of these works would have to be lowered. This last operation would, as every hydraulic engineer will understand, expose the stability of the works to considerable risk. Over and above all this, we should have to carry on the

summer and flood irrigation by means of these canals during the entire period that these existing changes were being made.

A Barrage North of Zifta would obviate all these difficulties. On the eastern bank, the main canals, which would utilise the water, have their heads on the river, and with a water level raised by 4 metres over its present level, would easily carry the increased supply. On the western bank, it would be necessary to excavate the feeder canal and build its head works. This canal would supply water to the Bahr-Shebîn and the Sahel canal, and would be an easy and economical work. We should interfere as little as possible with the present system of canalisation, and gain the great advantage of being able to maintain full supply levels far down the courses of the great arterial canals at the time of maximum demand. This would afford incalculable relief to the rotation system and simplify it immensely. Lastly we should be able to utilise the infiltration water which exists in the channel of the river itself, representing a discharge of from 2,000,000 to 3,000.000 metres cube per diem, and runs to waste at present.

For all these reasons, I pronounce most decidedly in favour of the construction of the Zifta Barrage. Mr. Foster estimates its cost and that of the works on the feeder canal at L. E. 400,000. This allowance is a liberal one for a work in the Damietta branch with its narrow section and raised bed.

In the Rosetta branch, the same arguments would apply in favour of a Barrage were it not that its bed is deeply scoured out, and no work constructed on it, in its upper reaches, would be of any use unless it held up 6 metres of water. Mr. Foster and I are at one in considering that the construction of a Barrage of such magnitude on the sandy bed of the river would be an exceedingly costly work, and one that would inspire no great confidence when completed. A work in the Nile subjected to a head of 6 metres of water would run such risks of failure that I do not consider myself justified in recommending it. How then are we to carry out our remodelling scheme? Mr. Foster discusses this question at length. For the western portion of the province of Garbieh, he proposes sundry alterations to the Baguriah and Qudaba canals in connection with the new feeder from Zifta to the Bahr Shebin. These alterations would meet the case, and although the system would not be so perfect as that proposed for the eastern branch of the river, yet, seeing that a Barrage in the western branch is out of the question, it is the only possible alternative.

The future irrigation of the Behera province will, under the circumstances, be a matter of extreme difficulty, and one demanding serious thought and consideration. This province is fed in summer by one single canal, the Rayyah Behera, which takes off from the upstream side of the Barrage; and the supplementary Barrage to the north has been found impossible. There are two ways of meeting the difficulty: we could return again to the system of feeding the canals from the Khatatbeh and Atfeh pumps, or we could widen

the Rayyah Behera, and its continuation the Khatatbeh, throughout their entire length. The first alternative would not, I think, be acceptable to the Egyptian Government, and I myself should not, for many reasons needless to detail here, recommend its adoption. There is no alternative then except the widening of the main canal.

This widening is possible, but taught by experience on this very canal, we know that the work should be undertaken very gradually and tentatively. The question of preserving a uniform section in the Rayyah Behera, as it traverses the sandy desert, is one of great difficulty. Mr. Foster has so successfully mastered the problem up to the present, that we may be confident of the proposed widening being successfully completed under his supervision, if he considers it feasible. At the same time, I am sure he will be the first to allow, that any project, which contemplates alterations in the section of this canal, is one not to be lightly undertaken. We have had experience of the ease with which its regimen may be upset, and of the supreme difficulty of restoration.

Admitting however that it can be and must be widened, if the Behera province is to reap the benefits of the increased supply, there still remains the question of the cost of this undertaking. Mr. Foster estimates it at L.E. 400,000. A proposal to spend so large a sum upon one single Province makes me pause, more especially when it is considered that this amount is exclusive of alterations and extensions of existing canals. At the same time, I see no other alternative, and as the extensions of cultivation on the Nubarieh canal and in the " Birea" lands will, in all probability, be on a large scale, they will, I think, justify me in having allowed this heavy sum to be added to the cost of our necessary works.

Mr. Foster's estimate for Lower Egypt is as follows : —

Damietta Barrage	L. E.	400,000
Widening Rayyah Behera	»	400,000
Improvements and extensions of canals	»	437,000
Drainage	»	470,000
Giseh Province	»	165,000
TOTAL	L. E.	1,872,000

Of these items, the first two have been already discussed and their necessity admitted. The third item might be reduced, as the proposed new Barrage north of Zifta will permit of most of the main existing canals carrying their increased supply without serious alteration. The expenditure will chiefly be incurred in the construction of new branch canals in the lands to be reclaimed. Now reclamation of land is a work that must necessarily progress very slowly, and many years will elapse before the whole of the area estimated for by us can be brought under cultivation.

The irrigation canals, which need only to keep pace with the reclamation, will not be constructed before the necessity for them arises, and in all probability, many of them will be carried out from the funds at our disposal in the annual irrigation grants. Under these circumstances, it is my opinion that a sum of L.E. 200,000 will suffice to make the necessary start in these works, and our Budget will provide the balance of the funds.

On the other hand I consider Mr. Foster's estimate for drainage as low, and I am increasing it by a sum of L.E. 100,000. Drainage works in Egypt are expensive, and are yet so absolutely necessary, that over-estimation is preferable to under-estimation.

The remodelling of Giseh province calls for no special remark. Mr. Foster has detailed all the necessary works in his note.

The estimate for the remodelling of the irrigation system of Lower Egypt, as altered by me, stands thus: —

Barrage in the Damietta Branch...............	L. E.	400,000
Widening the Rayyah Behera.................	»	400,000
Improvements and extensions of canals..........	»	200,000
Drainage...........................	»	570,000
Remodelling Giseh Province.................	»	165,000
TOTAL.....	L. E.	1,735,000

With the aid of the foregoing figures, we can calculate the additional sum, by which the estimated cost of the Nubian dam or the Wadi Rayyan will have to be increased, before the water supplied by them can be utilised.

(1) *In connection with a dam and reservoir in Nubia.*

Additional cost of the works needed for utilising the supply in Middle and Lower Egypt: —

Assyût dam..............................	L. E.	700,000
Middle Egypt............................	»	566,000
Lower Egypt............................	»	1,735,000
TOTAL.......	L. E.	3,001,000

(2) *In connection with the Wadi Rayyan reservoir.*

Additional cost of the works needed for utilising the supply in Lower Egypt alone: —

Assyût dam..............................	L. E.	800,000
Lower Egypt............................	»	1,735,000
TOTAL......	L. E.	2,535,000

I am now in a position to make the final selection of the projects whose execution I consider most advisable. I should place the different projects in the following order: — (1)

(1) A dam at R.L. 114.00m on the Assuân cataract.
(2) » R.L. 118.00m at Kalabsha.
(3) » R.L. 101.00m at Silsila.
(4) The Wadi Rayyan project.

With regard to the dam on the Assuân cataract, I place it first solely from the advantages it offers from an engineering point of view. I am quite aware that the difficulty regarding the Philæ temple is a very serious one, and one that will very possibly, I might almost say probably, involve the rejection of the project. This is a question for the Government to decide. I have placed Kalabsha second in the list because I consider it more advisable to build upon granite than upon sandstone; were it not for the fact that the rock at Silsila is sandstone, I should have given the Silsila dam the second place. I have given the Wadi Rayyan the last place for the reasons detailed in the preceeding pages of this note.

The following table gives the comparative sums required for the complete execution of the different projects.

NAME OF THE RESERVOIR	COST OF THE RESERVOIR	COST OF THE WORKS FOR THE UTILISATION OF THE WATER	TOTAL COST
I Assuân	L.E. 1,600,000	L.E. 3,001,000	L.E. 4,601,000
II Kalabsha	» 1,600,000	» 3,001,000	» 4,601,000
III Silsila	» 1,650,000	» 3,001,000	» 4,651,000
IV Wadi Rayyan	» 2,727,000	» 2,535,000	» 5,262,000

Any one of the first three projects would take 7 years to complete; the fourth would take from 3 to 4 years. But, as has been shown, could not be used under 10 years. The estimates for the dams are liberal as regards the designs submitted. They are however necessarily liable to modification, should the technical commission recommend serious changes. In the case of Kalabsha and Silsila, there is a possible further modification if the levels of the sound rock, as disclosed by the final borings now in hand, differ much from the levels assumed in the estimates. These borings, as already remarked, will be completed before the arrival of the commission. Considering the very special character of these works and the possibility of additional unforeseen expenditure arising, I have decided to allow a sum of 20 per cent for contingencies instead of the 10 per

(1) I have omitted the Philæ dam altogether from the above list: for the reasons detailed on pages 23 and 24 of this note, I think its construction inadvisable.

cent entered in Mr. Willcocks' estimates. The total costs of the different projects given above will then become:

I.	Assuân........................	L.E.	4,696,000
II.	Kalabsha......................	»	4,707,000
III.	Silsila........................	»	4,729,000
IV.	Wadi Rayyân.................	»	5,262,000

My note has assumed dimensions which I had not at first anticipated, but I have found it impossible to make it shorter without sacrificing many of the arguments which have led me to my final conclusion. The result at which I have arrived is very much the same as the conclusion come to by Sir C. Scott Moncrieff and Colonel Ross in their note of 1891 on this subject. My task has been easier than their's, inasmuch as I have had before me the result of two years' further study on the part of Mr. Willcocks and his staff.

The responsibility of making the final recommendation to the Government of Egypt will lie with the members of the Technical Commission, and will may feel confident that the course they will advise us to follow will be the one best calculated to serve the interests of the country.

I myself trust that a reservoir will ere long be a feature in the irrigation system of Egypt, and that the successful completion of one work will have such marked effects on the agricultural prosperity of the country that the Government will be encouraged to undertake even bolder schemes. At the head of the second cataract, we have a possible site for storing water, and at the third cataract, it may be possible to so regulate the high floods of the river as to protect Egypt from every fear of inundation. I think then we may confidently predict that, if a reservoir be successfully constructed, it will be only one of a chain which will eventually extend from the First Cataract to the junction of the White and Blue Niles at Khartoum. This question however is beyond the scope of the present note in which I have most strictly confined myself to a consideration of the country north of Wadi Halfa, and I conclude with Lord Cromer's words on this subject taken from his note of 1893: "What is wanted is that Egypt shall have the best possible Reservoir, whether it be in the Wadi Rayyan, or in the Nile valley itself, formed by means of artificial dams".

Cairo, 27th December, 1893.

W. E. GARSTIN.

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PERENNIAL IRRIGATION AND FLOOD PROTECTION

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APPENDICES.

PLATES.

REPORT ON PERENNIAL IRRIGATION AND FLOOD PROTECTION FOR EGYPT.

1. — Of all the methods which Egypt has ever employed for the increase of her material wealth, there is only one which has never failed her. Whenever the country has turned to the Nile it has not been disappointed. It was so 4000 years ago when the problems of water storage and flood control engaged the attention of the Pharaohs of the 12th dynasty. It is so to-day. All those dynasties in Egypt which have grappled with drought and inundation, the two great enemies of their country, have insured the happiness of their people and deserved well to be remembered in history. When therefore at the beginning of this century Mehemet Ali merged the Egyptian question into the irrigation question, he followed in the steps of the very greatest of his predecessors and laid deep the foundations of his country's prosperity. Since his day Egypt has steadily persevered in the path laid out for her by his masterful hand, and to-day we are considering the question of extending, to the whole valley of the Nile, the perennial irrigation and consequent intense cultivation which he gave to part of the Delta, and of insuring, for this future wealth, an immunity from the terrible evils of inundation. **Introduction.**

2. — This problem of providing perennial irrigation and protection from flood resolves itself into ten distinct heads : — **Subjects considered in this Report.**

I. The probable benefit to the country of an introduction of perennial irrigation.

II. The quantity of water needed, and the times at which it is needed.

III. The best methods of insuring this supply, and the probable cost of the works.

IV. The effect, on the magnitude and duration of the floods, of a substitution of perennial irrigation for the present system of intermittent irrigation.

V. The best method of controlling the floods, and the cost of the undertaking.

VI. The effects on the quality of the water when the new changes are introduced.

VII. The methods of utilising the perennial supply when it is obtainable, and the cost.

VIII. The provision for the effective drainage of the country when it is under perennial irrigation, and its cost.

IX. The effects, on navigation, of the proposed modification of the regimen of the Nile.

X. The possible effect, on the sandy desert bordering the Nile valley, of a change in the present system of irrigation.

3. — In this report an effort will be made to completely master the first six heads into which the enquiry is divided, and to consider the remaining four, only in their relation to the others. It is not to be gathered that the last four heads are of small importance because they have been subordinated to the others. Some of them are of such magnitude that on their right handling depends the future of the country, but experience and example have taught us how to act with respect to them, and they form the staple of our daily work. As to how we should deal with them, we need no extraneous advice, and ask none.

Drainage.

4. — During the early years of my work in Egypt, I was so forcibly struck by the damage done, to the perennially irrigated tracts, by the oversaturation of the soil, that I devoted a large part of my book on Egyptian Irrigation to the condemnation of this system of irrigation in Upper Egypt (1). Since then, however, I have seen the wonderful transformation of the country, by nine years steady and persistent effort to improve the drainage, in the face of continued discouragement. This transformation indeed seemed so slow in coming that for long it appeared chimerical, but to-day it is an established fact. Guided by my friend Professor Benetti of Bologna, I have seen the heavily irrigated, perfectly drained and rich valley of the Po. I have learnt how drainage preceded irrigation in Lombardy (2), and why it is that the most heavily irrigated country in the world is also, after hundreds of years, the richest agricultural tract in the world. I have also learned that, in China, perennial irrigation has been practised for thousands of years, and not for only half a century, as in Egypt, and that the land there retains its full strength and fertility. In this latter country also, Chinese historians record how drainage came first and irrigation afterwards (3), and that, in consequence, they have had none of those difficulties which, in India and Egypt, face the canal engineer at every step. We know now that, in future, drainage works must precede irrigation works in Egypt, and we can recommend a comprehensive scheme of perennial irrigation without any misgivings.

(1) « Egyptian Irrigation ». London, 1889, pages 82, 123, etc.
(2) « Hydraulique agricole ». Nadault de Buffon, I, 252-268.
(3) « Hydraulique agricole ». Nadault de Buffon, II, 555. « Congrès de l'utilisation des eaux ». Paris 1889, pages 310-323.

I. — Tho probable benefit to the country of an introduction of perennial irrigation.

5. — Owing to the absence of rain, the agriculture of Egypt depends entirely on irrigation. The year is divided into three seasons: summer, flood and winter (1). The first season is the summer, which extends from the 1st of April to the end of July, while the Nile is at its lowest and the water most valuable. The summer is followed by the flood season, which lasts from the 1st of July to the 30th November, when the Nile overflows its banks. The third season is the winter, during the months of December, January, February and March, when the Nile is confined within its channel, but carries a supply in excess of agricultural requirements. The summer crops are cotton, sugar cane, millets, rice, vegetables and fruit. The flood crop is maize or millets; while the winter crops are wheat, beans, barley, vegetables, peas and clover. Certain parts of Egypt enjoy perennial irrigation and can always insure two or three crops per annum. Others enjoy perennial irrigation only in good years, when the Nile in summer has a plentiful supply; while the rest of the country is irrigated only in flood. The perennially and semi-perennially irrigated tracts are intersected by numerous canals and bear the character of any heavily irrigated country. The lands which receive irrigation only in flood are either under millets if they are high-lying, or inundatel with water if they are low-lying and are therefore called « basins ». The water from these basins is drained off at the end of the flood, and

Agriculture in Egypt.

« As it ebbs, the seedsman
« Upon the slime and ooze scatters his grain
« And shortly comes to harvest. »

The harvest he reaps is the winter crop of wheat, beans or clover.

6. — The cultivated area of Upper Egypt, or Egypt south of Cairo, is 2,215,000 feddans or acres. Of this area 460,000 acres are at present considered as provided with perennial or semi-perennial irrigation, while 1,755,000 are irrigated only in flood. The summer crop of Upper Egypt may be estimated at 280,000 acres yielding L. E. 2,800,000; the flood crop at 530,000 acres of maize or millets yielding L. E. 1,600,000; and the winter crop at 2,010,000 acres valued at L. E. 7,035,000; while there are 2,600,000 date trees yielding L. E. 780,000 per annum. The annual yield of the 2,215,000 acres may be taken at L. E. 12,215,000 or L. E. 5.50 per acre.

Upper Egypt.

(1) « Egyptian irrigation » pages 36-118. Proceedings of the Institution of Civil Engineers, London Vol. 88, page 300 and Vol. 90, page 240.

7. — If perennial irrigation were provided for the whole of Upper Egypt, the extent of the summer crops would be 750,000 acres yielding L.E. 7,500,000, while the winter crop would be reduced to 1,545,000 acres valued at L. E. 5,410,000. The flood crop would rise to 900,000 acres valued at L. E. 2,700,000 and the dates would remain unchanged. Ths total annual yield would become therefore L. E. 16,390,000 or nearly L. E. 8 per acre. The annual gain to the country would be L. E. 4,175,000.

Lower Egypt.

8. — The cultivated area of Lower Egypt, or Egypt north of Cairo, is 2,740,000 acres. The whole of this area is provided with perennial or semi-perennial irrigation. There are 1,000,000 acres under summer crops yielding L. E. 10,000,000 per annum; there are 1,200,000 acres under flood crops yielding L. E. 3,600,000; and 2,100,000 acres under winter crops yielding L. E. 6,300,000. There are also 1,000,000 date trees yielding L. E. 200,000 per annum. The greater part of the land is double cropped, and the yearly yield of 2,740,000 acres may be taken as L. E. 20,000,000 or L. L. 7.30 per acre.

9. — Besides the cultivated land in Lower Egypt, there are 1,200,000 acres of land to the north which are lying in a state of swamp, or as dry salted plains. In whatever state they are, they are capable of reclamation. The carbonates and sulphates of soda and potash (known as « reh » in India), which are destructive of all vegetable life, are present only in very small quantities indeed, and however slow reclamation may be at the very worst places, it is nevertheless certain. It will readily be understood that, since Nile mud is the detritus of volcanic rocks, while the two salts above mentioned come principally from metamorphic and plutonic rocks, the salts cannot exist in any quantity in Egypt. If the ancient basin system could be reintroduced into these lands, they might be reclaimed by the Nile flood, and the area of Egypt might be increased to what it was in Roman times. This might have been accomplished if Lower Egypt had been still under basin irrigation, and the canals veritable rivers. The present canals are so small and contracted that basin irrigation cannot be reintroduced into these low lands except on an insignificant scale. The only other method of reclaiming the lands is to provide perennial irrigation and introduce the cultivation of rice and cotton.

10. — If perennial irrigation were provided for the whole of the cultivated land of Lower Egypt, and the better half of the swamped and salted land, the gain to the country might be estimated as follows: — the insurance of the cultivated land from drought may be put down at the moderate figure of L. E. 250,000 per annum. The 600,000 acres of reclaimed land would yield summer and winter crops worth L.E. 3 per acre. That is, the total gain to the

country would be L. E. 2,050,000 per annum, and the total yield of Lower Egypt would be increased from L.E. 20,100,000 to L.E. 22,150,000 per annum.

11.— Taking Upper and Lower Egypt together, the present cultivated area of 4,955,000 acres yielding L.E. 32,315,000 would be increased to 5,555,000 acres yielding L.E. 38,540,000 or a net gain to the conntry of L.E. 6,225,000 per annum. As in this Report however, that part of Upper Egypt which lies to the north of Assiout on the left bank of the Nile, and which has an area of 1,200,000 acres will be considered separately from the rest of Upper Egypt, it is as well to subdivide the net gain to the country. The improvement of Lower Egypt will yield L.E. 2,050,000 per annum, of Upper Egypt north of Assiout L.E. 1,500,000 and of Upper Egypt south of Assiout L.E. 2,675,000. Since Lower Egypt is already provided with regulating weirs across the Nile, and a complete system of perennial canals and drainage cuts, the perfection of its irrigation system will be the easiest and might first be undertaken. Upper Egypt, north of Assiout, has the most difficult and costly of its canals completed, but needs a weir across the Nile at Assiout and it might be taken in hand after Lower Egypt. That part of Upper Egypt which lies to the south of Assiout needs both weirs and canals and should naturally be dealt with after the others. **Upper and Lower Egypt.**

12. — I have so far considered only the direct gains from perennial irrigation, I now come to a new industry which has yet to be introduced into Egypt and which accompanies such irrigation in the sub-tropical regions of China, I mean pisciculture. I preface my remarks by a quotation from General Tcheng-ki-tong's paper read at the Paris International Congress in 1889 (1) : **Pisciculture.**
« I may add that, without these gigantic irrigation works, the Chinese could
« never have carried to such a point of perfection one of their most important
« industries. I speak of pisciculture. Thanks to the abundance of water, the
« whole of my countrymen, instead of contenting themselves with covering with
« their fishing boats, the seas, rivers and lakes of our country, have devoted
« themselves to the breeding of fish. The spawn is everywhere carefully collected;
« far from leaving it to take its chance the peasant gives this source of wealth
« a safe shelter in some spot where a perennial supply of water can be assured.
« The irrigation reservoirs team with fish. During winter the rice fields are
« fallow; the water is let into them and they are instantly full of carp. This
« industry allows us to make fish a considerable factor in the food of our people.
« The fish are either eaten fresh; or salted and dried, they are despatched
« to all parts of the Empire and sold at a price which is remunerative though
« it is exceedingly cheap ».

(1) « Congrès de l'utilisation des eaux ». Paris 1889, page 320.

13. — When we consider the wanton destruction of myriads of young fish which goes on yearly in winter in Egypt, and the entire absence of any attempt to breed them, we may with safety predict the creation of a new and very important industry in Egypt, when once a plentiful supply of water is assured. This will especially be the case if the basin reservoirs, to be hereafter described, are as successful as I anticipate. The Egyptian Government might indeed begin at once with experiments on a small scale in the Fayoum and in the Berea with one or two of the superior kinds of fish in the existing perennial canals and lakes.

II. — The quantity of water needed, and the times at which it is needed.

Duty of water.

14. — By a series of careful experiments it has been determined that the minimum quantity of water needed for the efficient irrigation of an acre of cotton is 17 cubic metres per day in summer delivered in the field (1). By a different set of observations on the irrigating power of canals we have found that in Egypt an allowance of 5 cubic metres per day per acre irrigated must be made for evaporation, absorption and waste. Adding these together, we find that 22 cubic metres per acre per day (about 1 cubic foot per second per 100 acres) should be provided for cotton or any other dry crop during the height of the summer irrigation. For wet crops like rice a supply of 40 cubic metres per acre per day is required in summer and flood. For winter crops a supply of 11 cubic metres per acre per day is required. It is assumed that $\frac{1}{3}$ of the total cultivated area is under summer crops like cotton, while $\frac{1}{3}$ of the reclaimed area is under rice summer. During flood the whole area requires irrigation. In winter the demand depends on the frost. Taking these calculations as a base, I have worked out the following table of the requirements of perennial irrigation in Egypt. A canal providing efficient irrigation should be capable of discharging as follows at the time of maximum demand. In winter 11 cubic metres per day per acre commanded. In summer $\frac{1}{3}$ of 22 or 8 cubic metres per day per acre commanded if the crops are cotton and sugar cane, and $\frac{1}{3}$ of 40 or 13 cubic metres per day if the crop is rice. In flood 25 cubic metres per acre per day for cotton, sugar cane and maize, and 40 cubic metres per acre per day for rice.

Times of demand for water.

15. — The above figures apply to the time of maximum demand. It remains to consider the state of the demand throughout the year. In both Upper and Lower Egypt, the demand decreases from the 1st of November to the 1st of December and is very slack during the latter half of December and the whole of January and February, unless there is frost. During March the demand increases steadily for the sowing of the summer crop, but the area of this crop

(1) « Egyptian irrigation » — pages 234, 235, &c.

is very much under the winter crop. The demand goes on increasing steadily through April and May, while, at the same time, the area to be irrigated is decreasing. There is a maximum demand in June for the summer crops while no winter crops are on the ground. From the 1st of July begin the early maize sowings and there is an increase in the demand, which becomes very acute about the 15th July everywhere except in the rice lands, where the heavy summer demand which had begun on the 1st May does not become acute before the 1st August. Through August, September and October there is a maximum demand for the whole area. Summing up our information we may tabulate it as follows:—

Cubic metres of water required per day per acre commanded.

	Lower Egypt. Cultivated.	Lower Egypt. Reclaimed.	Upper Egypt.
January	8	4	8
February	8	4	8
March	8	4	8
April	8	4	8
May	8	13	8
June	8	13	8
July 1st to 15th	13	13	13
July 16th to 31st	25	13	25
August	25	40	25
September	25	40	25
October	25	40	25
November	11	11	11
December	8	4	8

16. — The total discharges in cubic metres per day needed for Lower Egypt, Upper Egypt north of Assiût, and Upper Egypt south of Assiût, on this assumption, are as follows:— **Quantity of water needed.**

	Lower Egypt.	Upper Egypt. North of Assiût.	Upper Egypt. South of Assiût.
January	24,500,000	9,600,000	9,600,000
February	24,500,000	9,600,000	9,600,000
March	24,500,000	9,600,000	9,600,000
April	24,500,000	9,600,000	9,600,000
May	30,000,000	9,600,000	9,600,000
June	30,000,000	9,600,000	9,600,000
July 1st to 15th	44,000,000	15,600,000	15,600,000
July 16th to 31st	75,000,000	30,000,000	30,000,000
August	92,000,000	30,000,000	30,000,000
September	92,000,000	30,000,000	30,000,000
October	92,000,000	30,000,000	30,000,000
November	34,000,000	13,000,000	13,000,000
December	24,500,000	9,600,000	9,600,000

Converting these into cubic metres per second we have :—

	Lower Egypt	Upper Egypt North of Assiût.	Upper Egypt. South of Assiût.
January	300	110	110
February	300	110	110
March..............	300	110	110
April...............	300	110	110
May	350	110	110
June..	350	110	110
July 1st to 15th	510	180	180
July 16th to 31st......	900	350	350
August..............	1,100	350	350
September...........	1,100	350	350
October.............	1,100	350	350
November...........	400	150	150
December...........	300	110	110

Supply available for irrigation

17. — Taking 1877-78 and 1888-89, which are the two worst years on record, we find that the amount of water in cubic metres per second available for irrigation in a very bad year is as follows :—

	Lower Egypt.	Upper Egypt. North of Assiût.	Upper Egypt. South of Assiût.
January	300	110	110
February	300	110	110
March..............	300	110	90
April...............	275	90	..
May	245	25	..
June...............	225	25	..
July 1st to 15th.......	215	25	..
July 16th to 31st......	525	175	350
August.............	1,100	350	350
September...........	1,100	350	350
October.............	1,100	350	350
November...........	400	150	150
December...........	300	110	110

Supply needed from reservoirs.

18. — Comparing the quantities needed with the quantities available we see that the deficiencies in cubic metres per second are as follows :—

	LOWER EGYPT.	UPPER EGYPT. North of Assiût.	UPPER EGYPT. South of Assiût.
January	..	..	..
February	..	..	..
March	..	..	20
April	25	20	110
May	105	85	110
June	125	85	110
July 1st to 15th	295	155	180
July 16th to 31st	375	175	..
August	..	..	..
September	..	..	..
October	..	..	..
November	..	..	..
December	..	..	..

19. — With an extraordinary maximum discharge of 630 cubic metres per second and an ordinary discharge of 320 cubic metres per second, the reservoirs will have to supply the following quantities of water per annum : —

	LOWER EGYPT.	UPPER EGYPT. North of Assiût.	UPPER EGYPT. South of Assiût.
March	..	..	60,000,000
April	70,000,000	60,000,000	290,000,000
May	280,000,000	230,000,000	290,000,000
June	330,000,000	230,000,000	290,000,000
July 1st to 15th.	340,000,000	200,000,000	230.000,000
July 16th to 31st.	480,000,000	230,000,000	..
Per annum	1,500,000,000	950,000,000	1,160,000,000

For Lower Egypt therefore we need a reservoir capable of supplying 1,500.000,000 cubic metres per annum with a maximum discharge of 375 cubic metres per second. For Upper Egypt North of Assyût we need a reservoir capable of supplying 950,000,000 cubic metres per annum with a maximum discharge in July of 175 cubic metres per second. For Upper Egypt South of Assyût we need a reservoir capable of supplying 1,160,000,000 cubic metres par annum with a maximum discharge in July of 180 cubic metres per second. The total supply needed for the whole of Egypt is 3,610,000,000 cubic metres per annum, with a maximum discharge in July of 630 cubic metres per second.

20. — As we have taken a minimum year in making our calculations and provided sufficient water to insure a good harvest under the most unfavourable circumstances, we may count on being able to dispose of a more liberal **The sources of the Nile.**

supply in average years and years above the average. The importance of this liberal irrigation to the wealth of a country is well borne out by the condition of Lombardy, where a supply of 35 cubic metres per day per acre is available for general crops and 85 cubic metres per day per acre for rice, and where the advantages of this plentiful supply are everywhere apparent (1). A supply, such as this, and conditions, such as Lombardy enjoys, can be secured for Egypt by no systems of reservoirs in Egypt itself. If we wish to secure these great advantages for Egypt, we must regulate the supply issuing from the vast lakes which constitute the sources of the Nile. There alone we deal with quantities of water which approach these figures (2). In Egypt itself, however, we possess the means for storing (at a comparatively high cost certainly) all the water which is needed to provide the whole valley of the Nile with perennial irrigation on a scale not less liberal than that enjoyed by the perennially irrigated provinces of Egypt to-day.

III. — The best methods of insuring the required supply and the probable cost of the works.

Reservoirs.

21. — We have now to consider the methods of insuring the required supply of water to Egypt. Water may be stored in reservoirs in the valley of the Nile, in depressions in the deserts outside of the Nile valley, and in waste lands in the Delta. For the present I shall consider only those reservoirs which are situated in Egypt itself and in that part of Nubia which is under the Egyptian Government. Later on I shall return to the natural reservoirs which are not under the Egyptian Government.

Reservoirs in the valley of the Nile.

22. — Reservoirs in the Nile valley can be formed by constructing, at places where a suitable rocky bed is available, solid submergible dams over whose crests the river in flood may discharge itself; or by constructing solid insubmergible dams and turning the Nile over waste weirs; or thirdly by building insubmergible dams provided with numerous undersluices capable of discharging the flood waters without any material interference.

Solid submergible dams.

23. — Of solid submergible dams there is a considerable number in existence, but they have been generally built on inconsiderable streams. The Turloch dam in California and the Betwa dam in India have however been constructed on considerable rivers. The Turloch dam is 102 metres long and has a maximum height of 40 metres with a maximum depth of water over the crest of 1.5 metres (3). The floods there must be rare and of short duration or

(1) "Hydraulique" Nadault de Buffon I. 225, 270-276.
(2) Appendix III.
(3) Manual of Irrigation Engineering, Wilson, New York, 1893, page 295.

the work could not stand. The Betwa dam is 1080 metres long and has a maximum height of 18 metres with a maximum depth of water over the crest of 5 metres (1). At the Betwa dam the cross section is so designed that the water flowing over the dam in flood cannot strike the downstream face, while at Turloch the flood waters flow down the face of the dam. On a river like the Nile, whose floods are considerable and long duration, I think that a solid submerged dam 12 metres in height is the highest which could be built with security. The downstream face of such a dam could be made vertical or nearly so, and there would consequently be no action on it.

24. — Of solid insubmergible dams with waste weirs there are very many examples in existence. The earliest works of this kind are in Spain, while in France, dams were first built on the modern scientific principle of width proportional to pressure. The whole question of dams of this type has been exhaustively treated by the Italian Engineers Zoppi and Torricelli (2), while Appendix I contains an epitome which I have made in English of their valuable works. Such dams are built at times of considerable height; e. g. the new Puentes dam in Spain is 72 metres above its base, while 50 metres is quite an ordinary height nowadays.

Insubmergible dams with waste weirs.

25. — All solid dams are provided with small scouring sluices for the purpose of scouring out the mud which has deposited in the reservoirs owing to the ponding up of the rivers in flood. These sluices have however been a conspicuous failure on all muddy streams except where the reservoir is very narrow and has its bed on a very steep slope (3). At the 1889 Paris International Congress for the utilisation of rivers, Mr. Llaurado, a Spanish Engineer, stated that in a few years the Puentes reservoir had silted up to a vertical height of 14 metres, while the Nijar reservoir had silted up to the very top of the dam (4). Two reservoirs in Algeria have been conspicuous failures owing to the same cause (5). Indian irrigation literature teams with this subject. When we have to do with a river like the Nile which has a slope of $\frac{1}{13000}$, which occasionally runs liquid mud in August, and is heavily charged with matter in September and October (6), we may safely predict that any works, which materially interfered with the flow of the water in flood, would immediately cause a heavy deposit of silt and steady obliteration of the reservoir. We may have an idea of the amount of silt the Nile is capable of

The silting up of reservoirs.

(1) Public Works Department. N. W. P. India. Proceedings July 1888.
(2) Laghi artificiali dell'Algeria, della Francia e del Belgio. Roma 1886.
Laghi artificiali e irrigationi della Spagna. Florence, 1888.
(3) See Appendix I.
(4) Congrès de l'utilisation des eaux fluviales. Paris 1889, pages 7 and 8.
(5) "Les Irrigations" A. Ronna. Paris 1888. Vol. I, page 521 and the first part of Appendix I.
(6) Proceedings of the Institution of Civil Engineers, London. Vol. 90, page 244.

depositing if we consider that, during an average flood at Assuân, the Nile carries in suspension (1)

In August	11.71	cubic metres of solids per second
In September	5.33	» » » »
In October.	2.75	» » » »
In November	1.42	» » » »

or say 55,000,000 cubic metres in four months. The reservoir would be descreased by this amount per annum, while the soil of Egypt deprived of this rich mould would become poor indeed. We may look at the question from another point of view. Judging from observations on the Assuân and Cairo gauges we estimate that the soil has risen 0.12 metres per 100 years on 5,000,000 acres or 24,000,000 cubic metres per annum. I also estimate that 36,000,000 cubic metres of mud reaches the sea per annum, (1) so that the mean discharge of solids per annum at Assuân may be taken at 60,000,000 cubic metres. These quantities are so serious, whichever way we look at them, that they exclude any hope of constructing solid dams of the ordinary type (2) in the valley of the Nile downstream of the Atbara junction.

Insubmergible dams with numerous undersluices.

26. — It now remains to consider the 3rd class of reservoir dams, namely insubmergible dams with numerous undersluices capable of discharging the flood waters without much more interference than the silt of an ordinary rapid on the Nile. With such dams the muddy flood waters will be able to pass on without parting with their silt, and when the comparatively clear winter supply has commenced to flow, the sluices in the dam will be gradually closed and the excess water in the river stored for use in summer. When I wrote my first report on dams on the 1st May 1891 (3) I thought that the idea was a novel one ; since then however I have heard of the Bhatgarh reservoir dam on the Nira river in Bombay, and have before me the report on the work (4). On page 16 of that report, there is a quotation from a letter of Col. Fife, written in 1889, in which he recommends that the dam be constructed with numerous undersluices so that floods with their silt might be passed through it and thus obviate the silt difficulty. Mr. Whiting, the engineer in charge of the design, designed and built the dam with 15 sluices of 2.4 1.2 metres, spaced 5 metres apart. The sills of the sluices are from 5 to 11 metres above the foundation level of the dam and 26 metres below highest flood level or high water level of the reservoir which is one and the same. For high floods, there are two waste-weirs with a joint waterway of 243 metres 2.5 metres, with their sills 2.5 metres below high flood level. The 15 undersluices are regulated by means

(1) End of Appendix III.
(2) Appendix I.
(3) " Nile Reservoirs ". Report by Sir Colin Scott Moncrieff, Col. Ross and Mr. Willcocks, Cairo 1891.
(4) Report of the Nira Canal Works. Bombay 1892, page 18.

of cast-iron gates worked by screw-gearing. After the 1st heavy floods in July, the river is discharged through the sluices with a head of from 1 metre to 4.5 metres and occasionally there has been a head of 13 metres on the sills of the sluices. It is estimated that the maximum velocity through the undersluices may rise to 18 metres per second (1), which seems very excessive. The whole design is extraordinarily bold and hardy. The section of the dam has not been increased at the undersluices. The ashlar work is 38 centimetres thick.

27. — For the Nile I propose a waterway of 2000 square metres in the undersluices and no waste weirs of any kind. The undersluices will discharge the whole flood and insure the reservoir from being obliterated. The mean maximum flood of the Nile at Assuân is 10,000 cubic metres per second and this will be discharged with a mean velocity of 5 metres per second and head of 2 metres ($v = .8\sqrt{2gh}$). The August flood of 8,000 cubic metres per second will be discharged with a velocity of 4.25 metres approximatively and head of 1.5 metres. An extraordinary flood of 14,000 cubic metres per second which comes two or three times in 20 years and lasts a few days will be discharged with a velocity of 7 metres per second and head of 4.25 metres. In the above calculations the velocities are taken at the section through the sills, while there is a drop of 50 centimetres in the floor immediately below the sills. The muddy flood discharge will be scarcely interfered with, and that is the principal point as far as the silting up of the reservoir is concerned. The granite ashlar undersluices will be capable of standing the velocities which the water will attain. **Waterway of undersluices in Nile dams.**

28. — After an inspection of the principal systems of regulation in Italy, France, England, India and Egypt (2), I am of opinion that the only system of regulation capable of working on the scale and under the conditions imposed on us in the Nile valley are Stoney's patent self balanced roller gates. I have seen these gates working in Ireland and England, and tested at Ipswich a pair of them for Holland. After a theoretical examination of the subject with Professor Benetti of the University of Bologna and an exhaustive practical examination with Mr. F. D. M. Stoney M. I. C. E., I have concluded that gates 2 metres wide and 10 metres high will best meet our requirements. With such gates under 22 metres head of water, the working pressure upon the rollers can be easily maintained at one third of a ton per lineal inch which is Mr. Stoney's safe limit (3). We shall also be able to dispense with arches and cover the sluices with granite lintels. All cut stone arches which are heavily loaded on the crown are liable to settlement, and leak when under a great head of water. A lintel is the safest and soundest covering when only ashlar is employed. **Undersluices.**

(1) Report on the Nira Canal project. Bombay 1892, page 18.
(2) Appendix II, contains my report on the different systems of regulation.
(3) Appendix IV, contains Mr. Stoney's report on the gates proposed for the dams on the Nile,

Calculations.

29. — Plates 2 and 3 give plans, elevations and sections of the gates unde 15 metres and 22 metres head of water respectively, while plate 13 gives the calculations on which the dimensions have been based. The centre of pressure with the reservoir empty or full is always in the middle third and the maximum pressure is 6.5 kilograms per square centimetre at the toe of the piers and 7.2 kilograms at the toe of the solid foundation below the undersluices. Appendix V gives Professor Hudson Beare's report on Egyptian stones, and the weights of the different kinds of masonry have been calculated accordingly. Full allowance has everywhere been made for the sluices. The class of masonry and the composition of the mortar are given in detail under each separate dam, while Appendix VI gives the results of experiments on Egyptian mortars.

Details of dams and undersluices.

30. — Since there are 2000 square metres of waterway to be provided as a minimum, it will readily be seen that this can be done in an infinite number of ways. I have everywhere taken the mean high flood of 10,000 cubic metres per second as the standard of reference and insured in every design that 2,000 square metres of sluice area will be drowned at this stage of the river. Working on these lines, some of the dams, especially the low ones, need only 2,000 square metres of waterway, while the high ones need 2,400 square metres. The dams will be everywhere constructed on living rock. Where the depth of water exceed 32 metres, the dam will be solid and of the section proposed by Professor Rankine (1). Where the depth of water is under 32 metres there will be provided some 70 or 80 undersluices $10^m \times 2^m$, with their sills under 22 metres head of water; and when the depth of water is under the 25 metres there will be provided some 30 or 40 undersluices $10^m \times 2^m$, with their sills under 15 metres head of water. Care will be taken that the sills of the undersluices are nowhere more than 10 metres above the foundation level. I consider this as the maximum height which is safe. Under this height the toe of the wall can be kept well retired from the action of the water which has issued through the undersluices in flood. When this height is exceeded, either the floor of the undersluices has to be lengthened, or the toe has to be advanced downstream in the wash of the seething water.

Proposed reservoir dam.

31. — Speaking generally I should thus describe one of the proposed dams for reservoirs in the valley of the Nile. The design for the work consists of a solid insubmergible dam pierced with 100 undersluices of $10^m \times 2^m$, and constructed on solid rock. The piers between the undersluices are 3 metres wide and every set of ten sluices is separated from the next by abutment piers 10 metres in width. I consider these abutment piers necessary in order to give

(1) Miscellaneous Scientific papers — Rankine. London 1881, page 550.

a knotty structure to the dam. The dam however is strong enough to resist the maximum pressure on it without their aid. The floor, the faces of the piers, the lintels, and the cutwaters up to flood level are of the best granite ashlar. There is no arch work of any kind in the dam. The design is in keeping with the ancient buildings in the neighbourhood, whose architecture lends itself eminently to the massiveness of a reservoir dam. All the undersluices are regulated by Stoney's patent balanced roller gates. During the whole of the flood, the gates will be fully open and the flood waters of the Nile will be discharged through the undersluices. The navigation is effected through locks blasted out of the living rock in great part, and with channels well retired from the up and downstream action of the dams. There is a double lock of $75^m \times 12^m$ and a total head of 25 metres divided into 12 and 13 metres. The gates are exceedingly high but not more massive than those proposed for the locks blasted out of the living rock for the Nicaragua Canal (1), while the area of the gates is by no means excessive compared with those now constructed for important docks (2). In the estimates, however, I have allowed for 4 lifts of 6 metres each. Hydraulic lifts are out of the question when we have to deal with steamers such as ply on the Nile.

Regulation at the dams.

32. — The regulation at the dams will be performed in the following manner. When the flood has passed and the comparatively clear winter supply has begun to flow, the lower undersluice gates will be gradually lowered until the water begins to rise and flow through the higher sluices. When the water has risen to a height of from 3 to 4 metres above their floors and is 10 or 11 metres above the floors of the lower sluices, these latter will be completely closed and the whole river will be discharged through the higher sluices, which will now be gradually closed until the water in the reservoir rises to its full level. In closing the gates, care will be taken to divide the discharge of 1000 cubic metres per second equally between the 100 sluices, so that it may be broken up. If this is considered unadvisable, it will be easy to turn the minimum discharge of 520 cubic metres per second over a waste weir at a cost which may fairly be debited to the contingencies. When the reservoir has to be emptied, the reverse process will be performed. The higher sluices will first be opened and then the lower. The former will be worked under a maximum head of 15 metres, and the latter under a maximum head of 11 metres.

Times at which the reservoirs will be filled.

33. — I have stated that the reservoirs will be filled after the flood. It remains to be proved that there is a sufficient surplus of water in the Nile after the floods have passed to allow of the reservoirs being filled. I confine

(1) Proceedings of the Engineer's Club of Philadelphia, 1886, page 332, where details of the locks are given. The lifts vary from 8 metres to 16 metres and the widths are 20 metres.

(2) Minutes of the proceedings of the Institution of Civil Engineers, Vol. 101, page 129, and Vol. 111, pages 41 to 128.

the enquiry to the most unfavourable years. In a year like 1877 or 1888, the discharge of the Nile is in November 2500 cubic metres per second, in December 1700, and in January 1200 cubic metres per second. The requirements of irrigation are 700, 520 and 520 cubic metres per second respectively in the three months. But the free navigation of the Nile by the large steamers requires a discharge of 1000 cubic metres per second, so that the quantities available for storage are:—

In November	3,800,000,000	cubic metres
In December......	1,800,000,000	» »
In January.......	500,000,000	» »
TOTAL...	6,100,000,000	cubic metres

Since 3,610,000,000 cubic metres of water are only needed, it will readily be seen that, in the very worst years, there will be abundance of water to spare for the filling of the reservoirs in the valley of the Nile.

Geology of the Nile valley.

34. — As a description of the geology of the Nile valley would have occupied too much space in this report, I have collected all the information necessary for the right understanding of the project and put it into Appendix VII. On a geological matters I shall refer to it. I gladly record here my indebtedness to Professors Mayer Eymar, Schweinfurth and Sickenberger for the material help I have received from them.

Philæ and Abu Simbel.

35. — The existence of the two temples of Philæ and Abu Simbel has also to be taken account of in all questions connected with reservoirs, and I may state here that in deference to public opinion, which is against the sacrifice of the site of the latter temple, I have prepared my designs for reservoirs so as to leave the Philæ Temple entirely free from any possibility of inundation. Abu Simbel is far out of the reach of any reservoir.

History of the reservoir question.

36. — Before entering upon the detailed descriptions and estimates of the different reservoirs, I think it will elucidate the subject if I give a slight historical sketch of the reservoirs question. The fame of the ancient Lake Mœris had made a profound impression on the mind of Mehemet Ali and he urged on his Chief Engineer Linant Pasha (1) the necessity of undertaking similar works. Linant Pasha first set himself to discover the site of the ancient lake and then estimated roughly the cost of reconstructing it, but considered the cost prohibitive (2). He also recommended Gebel Silsila as a suitable site for a weir and canal head (3). The failure of the Barrage discouraged the Government from undertaking

(1) « Memoires sur les travaux publics en Egypt », by Linant de Bellefonds. Paris 1873, pages 418 & 419.
(2) » » » » » » » » » » 88 & 420.
(3) » » » » » » » » » » 397 & 398.

new works and the question dropped. In 1880 Count de la Motte[1], a Frenchman, took up the question of reservoirs and proposed a dam at Gebel Silsila and a reservoir to the south of it; the works were to have cost L. E. 4,000,000 exclusive of compensation and the reservoir was to have contained 7,000,000,000 cubic metres of water. As a counter project to this, Mr. Copé Whitehouse[2], an American gentleman, in 1882 suggested utilising the Wady Rayân a depression in the desert that had already been mentioned by Linant Pasha in his book [3] and located by him on his hydrological map. Financial difficulties and the supposed failure of the Barrage prevented the Egyptian Government at that time from seriously considering the question of reservoirs for increasing the discharge of the Nile as it had insufficient means of utilising the supply then existing. The subsequent success of the Barrage gave new life to the question of reservoirs, and, at the request of Sir Colin Scott Moncrieff, the Government deputed Col. Western, Director General of Works, to give shape to the suggestions made by Mr. Cope Whitehouse, to make plans of the Wady Rayàn and the deserts between it and the Nile, to find out the capacity of the reservoir and see if it could be utilised. Liernur Bey and a staff of Engineers were placed under his direction and they prepared the contoured map of the Wady Rayân and the surrounding deserts. Col. Western's report, plans and estimates were printed by Government [4]. Partly owing to financial considerations, but still more to the differences of opinion among the Officers of the Irrigation Department as to the feasibility of carrying out the project, the question was for the time shelved.

37. — Meantime the other project of Count de la Motte for reservoirs in Nubia was being studied, and on its being unfavourably reported on, owing to the mistakes in levels, in 1889 Mr. Prompt, a member of the Egyptian Railway Board, suggested utilising the trough of the Nile itself for a reservoir in the absence of the low plains which did not exist. As by this time the Barrage repairs were practically completed and the effect of the drainage cuts begun to be appreciatively felt, the Government, again at the request of Sir Colin Scott Moncrieff, decided to study the whole question of reservoirs anew and did me the honour of appointing me Director General of the Study. Messrs. Hewat, Roux, Clifton, stent, Amir Bey Abd el Bar, Abder Rahman Rushdy, Mohamed Shukri, Abdalla Hassib, Abdalla Rifaat, Mohamed Saber, Mohamed Balig and some other engineers were placed at my disposal, and this report and the plans which accompany it are the result of our labours. We have studied both the reservoirs in the valley of the Nile and in the depressions in the deserts outside of the Nile valley.

(1) « Le Nil » by the *Société d'études du Nil*. Date on the plan of the Semne Cataract by Mr. Cotterill.
(2) Bulletin of the American Geographical Society. 1882, N° 2, pages 22 and 24.
(3) « Mémoires sur les travaux publics en Egypte », by Linant de Bellefonds. Paris 1873, pages 53 and 57.
(4) Notes on the Wady Rayân, by Liernur Bey, Col. Western and Sir Colin Scott Moncrieff. Cairo, 1888.

Reservoirs in Nubia.

38. — North of Wâdy Halfa there are six possible reservoirs in the Nile valley itself:

(1) A low level reservoir South of Gebel Silsila.
(2) A high level reservoir South of Gebel Silsila.
(3) A low level reservoir above the 1st Cataract.
(4) A high level reservoir above the 1st Cataract.
(5) A high level reservoir at Kalabsha.

(1) AND (2) RESERVOIRS SOUTH OF GEBEL SILSILA.

General.

39. — The Silsila pass of the Nile, about 70 kilometres downstream of Assuân where the Nile runs between sandstone hills, is a possible site for a reservoir dam. Plates 5 and 6 give all necessary details. The Nile here, in ancient times, was split up into two channels by an island 2500 metres long and 1500 metres broad. The right hand channel was about 1500 metres wide and the left hand channel 350 metres. The former has silted up to a depth of from 8 to 12 metres above high flood level of to-day and the whole river now finds its way down the left channel. In the broad right hand channel, a line of borings taken across the valley to a uniform depth of 15 metres, has touched rock nowhere. It is proposed, should this site be selected, to construct an earthen bank 50 metres wide across the right hand channel with its top 5 metres above maximum water level of the reservoir. In the left hand channel, widened to 560 metres, it is proposed to construct a masonry dam with 100 undersluices each $10^{m} \times 2^{m}$. On the right bank will be excavated a navigation channel and on the left bank an irrigation canal. The greatest head of water on the earthen bank will be 8 metres. The greatest depth of water at the masonry dam will be 30 metres, and the maximum head of water 24 metres divided into two heads of 15 metres and 9 metres.

Geological.

40. — The rock is sandstone, the ordinary Nubian sandstone with strata of pudding and clay. The core of the island on the right bank is sandstone of great thickness with few strata of clay. There are however considerable fissures. The stone of the left bank and that below the level of the ancient quarries is not of the same character, and here clay strata are frequently met with. A head of 15 metres of water might be considered safe on this rock, and one might be bold enough to even allow a head of 20 metres of water, but beyond that is out of the question. I personally consider 15 metres as the maximum safe head of water. The deposit which has silted up the right hand channel is sand.

Profile of the dam.

41. — The R. L. of the sound rocky bed of the river at the site of the proposed dam may be taken at R. L. 74.00. High flood is R. L. 88. Low summer is R. L. 80.00. I have prepared two designs for this dam:

one holding up water to R. L. 100.00 and the other to R. L. 104.00. The minimum downstream water surface in the former case will be maintained at R. L. 85.00 by a massive dry stone weir downstream of the dam. In the latter case the minimum downstream water level will be maintained at R.L. 89.00 by a regulator on the dry stone weir. If the water is held up to R. L. 100.00 (plate 7 A) the earthen bank across the right hand channel will have on it a maximum head of 4 metres. There will be considerable leakage, but the bank will in my opinion be absolutely safe. It will be heavily pitched on its upstream side. The width at top will be 50 metres and the side slopes 1 ot 1 $\frac{1}{2}$. The left channel will be widenel to 560 metres and the masonry dam will have 80 openings under 22 metres head of water and 20 under 15 metres head of water. The gates will be of the pattern and the principle already described in paragraphs 26 to 32, and depicted in plates 2, 3 and 4. The dam will be rectilinear in plan. Upstream of the dam will be a masonry apron 3 metres wide, and on the downstream side there will be an apron of solid masonry, 2.50 metres deep and 30 metres wide, of the section shown on plate 5. This apron will protect the sandstone from the action of the water issuing from the undersluices. Its top course will be composed of roughly dressed granite laid in cement. (I should like to remark here that at the Assuàn quarries we have an enormous amount of roughly dressed granite blocks lying about. The ancients worked entirely with wedges and chisels and all the odd pieces which remain from their quarrying of 4000 years are fairly well shaped. The roads from the quarries to the Nile are in good order). Downstream of the apron will be a weir of packed dry sandstone 750 metres in length with its crest at R. L. 83.00, so as to maintain a backwater on the dam of R. L. 85.00 in the height of summer. The stone for the weir will come from the excavations. In the estimates, the cost of depositing this stone into the bed of the river has been added to that of the excavation. Such weirs become solid with deposit (cf. the St. Christophe dam in Appendix I page 10 and the part of the Barrage weir on the Nile where it closes the deep channel of the river) (1).

42. — If the water is help up to R. L. 104.00, the earthen bank across the right channel will have a maximum head of water of 8 metres and be well pitched on its upstream face. Being 50 metres wide (or 100 metres for the matter of that if 50 metres is considered insufficient) and 5 metres above high water level with side slopes of 1 to 1 $\frac{1}{2}$, it will, I hold, be safe. The left channel will be treated as before except that the downstream apron will be more solid. As I do not consider a head of 19 metres of water safe for Nubian sandstone I have designed on the crest of the weir downstream of the dam (plate 5) a regulator raising the water surface in summer to R. L. 89.00, and

(1) "Egyptian Irrigation" by W. Willcocks. London 1889, page 150.

thus reducing the head on the dam to 15 metres. The regulator will have 55 openings of 5 metres each with piers of 1.50 metres width and 6.50 metres height. The regulation will be performed by means of the steel girder horizontals and timber verticals so common in Egypt and described in Appendix II, page 19. This system is an excellent one where leakage is a matter of no concern. The floor of the regulator will be of masonry 20 metres wide and 3 metres deep built on the top of the stone pitching like the Barrages near Cairo. When the upstream water surface of the reservoir falls to R. L. 100.00, the verticals and horizontals will be completely removed and the openings will be left free for the flood. In this way I think the high level reservoir dam at Silsila may be made safe.

Navigation. **43.** — The navigation channel will be on the right bank and will be excavated out of the rock. The locks will be 75 metres long and 12 metres wide and have 2 metres of water on their sills as a minimum. The head of the lock channel is well removed from the draw of the dam, and the tail will be well protected from the wash by a long spur of stone. The upstream water surface will never be allowed to fall below R. L. 86.00. The designs show two locks with a total head of 24 metres, a maximum depth of 16 metres and a maximum head of 12 metres. If this is considered excessive, in spite of the fact that the locks are cut out of the living rock, it will be possible to make 4 locks with a head of 6 metres on each lock. The estimates allow of 4 locks being constructed.

Canal head. **44.** — The regulating head of the canal will be on the left of the dam. Ten openings of the canal head are shown on the plan as they aid the dam in providing 2.000 square metres of waterway when the Nile is discharging 10,000 cubic metres per second, and their cost is rightly debitable to the reservoir.

Masonry and construction. **45.** — The rubble masonry above water surface in summer will consist of limestone laid in mortar composed of 3 humra (pounded brick), 2 fat lime and I desert sand. The face work will consist of granite laid in mortar composed of 1 cement and 2 sand. The rubble masonry below summer water level will consist of a central core of limestone laid in ordinary mortar and 2 metres on either face of limestone laid in cement mortar with the face work of granite. All ashlar will be laid in mortar composed of 1 cement and 1 sand.

46. — The navigation channel, the irrigation canal and the 30 sluices under 15 metres head of water will be first constructed. Then the low level sluices will be constructed by dividing the river into two parts and building in half at a time. The water here in summer is so shallow that building will be

comparatively easy. I have however allowed L. E. 100,000 for cofferdams. The work will probably take 5 years to build.

47. — The capacity of the low level reservoir is 2,568,000,000 (1) cubic metres and its estimated cost L. E. 1,594,000 (2), of which L. E. 624,000 are for compensation. **Financial.**

The capacity of the high level reservoir is 3,774,000,000 cubic metres and its estimated cost L. E. 1,890,000 of which L. E. 670,000 are for compensation.

This water can be delivered at any rate desired, which is an advantage enjoyed by all the reservoirs in Nubia. The loss by evaporation will be 1 metre or 7 per cent.

By referring to Appendix VIII, page 7, it will be seen that a reservoir south of Gebel Silsila will inundate the town of Assuân.

(3) Low level Reservoir South of the First Cataract.

48. — It is proposed to construct the reservoir dam at the head of the firt cataract. Here we have an extensive outcrop of syenite and quartz diorite clean across the valley of the Nile. The river itself is broken up into numerous shallow channels, and we have sound rock everywhere at a very convenient level. This is the best site for a dam in Egypt. Unfortunately Philæ Island lies to the South of it and a high level dam would put the temple under water for some 5 months per annum. Plate 8 gives a general plan of the head of the Cataract and the islands to the South of it, while plate 9 gives plans and sections of the low level dam proposed for this site. On plate 8 are shown the levels of every part of Philæ Island. **General.**

49. — The main dam will be 1500 metres in length, on three curves springing from substantial buttresses. The extreme left hand channel, where there is a very solid bed of rock will be closed by a dam 300 metres in length. In these dams there will be 100 undersluices, each $10^m \times 2^m$. The narrow intermediary channel, improved by blasting, will be used for navigation. The site of the lock is not depicted with the exactitude employed at the other works, as the height of the water this winter prevented the Engineers from sounding the rapid. The total length of the different dams is 1850 metres. Of this length, 1150 metres will be solid and 700 pierced with undersluices. The greatest height of dam anywhere will be 23 metres and the greatest head of water 20 metres.

(1) For details See Appendix IX, pages 6 and 7.
(2) For details See Appendix VIII, pages 3 and 4.

Geological. **50.** — The rock is everywhere a hard and compact syenite or quartz diorite, except near the extreme left of the main channel where the diorite is compact but not very hard. Here the dam will be solid. A head of 100 metres of water might be put on this rock without any anxiety as to foundation.

Profile of the dam. **51.** — The reduced level of the bottom of the lowest of the 3 small channel cut through the syenite may be taken at 83.00 metres, the general level of the solid rocky crest of the cataract is at R. L. 91.00 metres; low summer is at R. L. 90.00 and maximum flood at R. L. 100.00. It is proposed to hold up the water to R. L. 105 or 106 metres. There will be 30 undersluices under 22 metres head of water and 70 sluices under 15 metres. The section of the dam, undersluices and regulating gates will be typical as shown on plates 2, 3 and 14.

Navigation. **52.** — The navigation channel will be between the large southern island and the smaller one to its immediate north. It will be removed from both the draw and the wash of the dam. The locks will be $75^{m} \times 12^{m}$ and have 2 metres of water on the sills as a minimum. The designs show two locks with a total head of 17 metres and a maximum depth of water of 14 metres, as they are blasted out of the living rock, but the estimates allow for four locks

Masonry and construction. **53.** — The rubble masonry will be everywhere above water surface and of the same consistency as that described at Silsila, except that the limestone will be replaced by granite. The passes where the water flows in summer are so narrow and shallow that construction here will be extremely easy. I have entered L. E. 30,000 in the estimates for cofferdams and L. E. 10,000 for clearing foundations. It will take four years to complete the work.

Financial. **54.** — The capacity of the reservoir is held up to R. L. 106.00 is 1,065,000,000 cubic metres, and if held up to R. L. 105, is 928,000,000 cubic metres. The cost of the reservoir will be L. E. 772,000, of which sum L. E. 114,000 are for compensation. The evaporation will be 1 metre or 7 per cent of the contents. The water can be delivered at any rate desired.

(4) High level Reservoir above the First Cataract.

General. **55.** — It is possible to construct reservoir dams across the channels between the granite islands upstream of Philæ Island so as to leave the temple untouched. These dams will of necessity be expensive as the main channel of the Nile is deep. On plate 8 the possible sites of these dams are marked.

The best series of dams would be those near Philæ Temple, but the main channel here has silted up and though boring in the middle have disclosed rock at about R. L. 75.00 still an estimate would be guess-work in great part and I think under the mark. I have therefore on, plate 10 made, designs for dams near the head of the South island where we have channels free from silt and where the areas will give us a true idea of what such a work will cost. The main dam on plate 10 is 600 metres in length and on a curve, while the dam on the left is 450 metres long and also on a curve. The deep channel of the main dam is closed by a solid masonry dam on a length of 450 metres. The maximum depth of water is 48 metres and the maximum head 28 metres. The navigation channel is on the right of the main dam, and on the left are 10 low level and 20 high level undersluices. The dam on the left is pierced by 70 low level and 20 high level undersluices.

56. — The rock on the right bank of the main channel right down to Philæ Islands consists of schists and diorites. The rock everywhere else is syenite or diorite, and the syenite increases as we advance northwards. The rock is well suited to stand any head of water up to 50 metres. **Geological**

57. — The R. L. of the lowest point in the main channel is 70.00 metres, the general level of the left hand channel is R. L. 90.00 metres. High flood is R. L. 100.00, low summer is R. L. 90.00. It is proposed to hold up the water to R. L. 118.00. There will be 80 undersluices under 22 metres head of water and 40 undersluices under 15 metres head of water. Both dams will be curved in plan. The sections of the solid dam and undersluices will be typical as show on plates 2, 3 and 14. **Profile of the dam.**

58. — The navigation channel will be on the right of the main dam. The locks will be $75^m \times 12^m$ and have 1 metre of water on the upstream sills at minimum water level, which will be R. L. 99 if the water is held up to R. L. 118, and R. L. 96 if the water is held up to R. L. 115. The design shows two locks with a total head of 28 metres, but the estimates allow for four locks to get over the lift of 28 metres if the water is held up to R. L. 118 and 25 metres if the water is held up to R. L. 115. **Navigation.**

59. — The masonry will be the same as that for the low level Assuân dam. It would be impossible to construct the dam at the head of the right channel in the open, but when built lower down near Philæ Temple (it will be remembered that I have placed the dam at the head of the channel in order to get a correct estimate) it will be possible. I propose first cutting away the rock and clearing the left hand channel by quarrying the stone in its bed and so inducing the Nile to send a much larger volume in that direction. **Masonry and construction**

The right hand channel could be closed with two stone dams with their crests at summer level and would sit up in flood. The silt could afterwards be dredged out and the foundation laid by means of cofferdams. This operation would be expensive and I have estimated L. E. 300,000 for cofferdams and pumping. The dam will take 8 years to build.

Financial.

60. — The capacity of the reservoir with the water held up to R. L. 118 will be 3,733,000,000 cubic metres and its estimated cost L. E. 2,100,000 of which L. E. 547,000 are for compensation. If the dam were built to R. L. 115,00, the capacity of the reservoir would be 2,792,000,000 and its cost L. E. 1,770,000 of which L. E. 350,000 would be for compensation. The evaporation will be 1 metre or 5 per cent.

(5) HIGH LEVEL RESERVOIR SOUTH OF KALABSHA.

General.

61. — About 2,500 metres south of the Kalabsha pass of the Nile, there is an outcrop of syenite and the Nile is divided into three channels by a number of islands. Here we have a possible site for a reservoir dam. The right hand channel is 120 metres wide, the central 30 and the left hand 140 metres. Plate 11 give a general idea of this reach of the Nile and plate 12 a plan and sections of the proposed dam. At the proposed site, we sounded everywhere on rock except at the extreme right of the left hand channel where there was a slight depth of coarse sand. The deep channel of the river 120 metres in length will be closed by a solid masonry dam, while the remaining parts will accommodate 80 low level and 40 high level undersluices. The greatest depth of water upstream of the dam will be 44 metres and the greatest head 25 metres if the water is held up to R. L. 118, and 41 and 22 metres respectively if the water is held up to R. L. 115. The rock is everywhere granite. The Kalabsha gate of the Nile, 155 metres wide and 30 metres deep in summer is unsuited for a reservoir dam both on account of its depth and the fact that it is at the downstream end of the granite, and immediately upstream of the sandstone.

Geological.

62. — The rock is everywhere syenite except on the extreme left bank where we have a very hard and compact diorite. The site is geologically a good one.

Profile of the dam.

63. — The deepest point of the right hand channel is R. L. 74, of the middle channel R. L. 90, and the left hand channel R. L. 84. I have prepared a design for holding up water to R. L. 118, but I have estimated for two dams, one holding up water to R. L. 118 and the other to R. L. 115. The minimum downstream water surface will be R. L. 93. I propose 80 openings under 22 metres head of water and 40 openings under 15 metres. The dam will be everywhere typical.

64. — The navigation channel will be on the right bank where we have a very convenient site for both intake and outlet. It will be 600 metres long and well protected from both draw and wash. The upstream water surface will never fall below R. L. 99 if the water is held up to R. L. 118, and R. L. 96 if the water is held up to R. L. 115. There will be 1 metre of water on the floor at the time of minimum supply. The designs show two locks with a maximum head of 25 metres, but estimates allow for 4 locks. Navigation.

65. — The masonry will be similar to that proposed for the low level Assuân dam. The dressed and squared granite will come from the Assuân quarries. The navigation channel will first be excavated and completed, and the right hand channel closed with stone dams up and downstream of the proposed work; these loose stone dams will have their crests at R. L. 93. After the flood the space between the dams will have silted up and be treated as proposed for the high level Assuân dam (1). The middle and left channel will be comparatively ease. I have allowed L. E. 250,000 for cofferdams in the estimates. The work will take 5 years to build. Masonry and construction.

66. — The capacity of the reservoir if held up to R. L. 118 is 2,733,000,000 cubic metres and its estimated cost L. E. 1,589,000 of which L. E. 432,000 are for compensation. The capacity of the reservoir if held up to R. L. 115 is 1,964,000,000 cubic metres, and its estimated cost L. E. 1,288,000, of which L. E. 240,000 are for compensation. Financial.

The loss by evaporation will be 1 metre or 5 per cent.

67. — Thinking that it might be possible to construct a dam across the Nile near the Gertassa Temple with a subsidiary weir at the head of the First Cataract, I had borings taken in the bed of the river near the temple. These borings have disclosed deposits of sand of over 20 metres in depth at a place where the sandstone is exceptionally good. They have dissipated completely all ideas of constructing dams in the sandstone reaches of the river above the First Cataract. Dams in the sandstone reaches of the river.

68. — We have now finished with the reservoirs in the valley of the Nile north of Wady Halfa, and have come to the depressions in the deserts outside of the Nile valley. After a careful examination of the deserts on both banks of the river between Wady Halfa and Cairo, I have found no depression capable of being utilised as a reservoir except the Wady Rayan. I omit the Wady Natrun in the deserts between Cairo and Alexandria. By its depth and size it might be suitable for a reservoir, but the existence of the large quantities of natron in its bed renders it unsuited for the storage of water for irrigation Reservoirs in the depression in the deserts.

(1) I think this method of working with exposed foundations for a dam is to be preferred to compressed air even if the latter is the more economical.

purposes. The other depressions are either at too high a level or not of sufficient extent. Along the course of the Bahr Yusuf from Dalga to Maiana, there are numerous small depressions (notably one to the south of Behnessa) which are capable of storing of a small quantity of water, but surveys and levels have proved them unworthy of serious consideration. There remains the Wady Rayan.

THE WADY RAYAN RESERVOIR.

General.

69. — Plate 15 gives the plan of the Wady Rayan, the deserts between it and the Nile valley, and the cultivated land. The plan was begun by Col. Western and has been completed by me. The Wady Rayan is a depression to the S. W. of the province of the Fayoum. Its lowest point in 42 metres below sea level. It is separated from the Fayoum by a limestone ridge which is generally from 34 to 60 metres above sea level except at two places where it falls to 26 metres above sea level on a length of 600 metres. At R. L. 27 the Wady and adjoining depressions have an area of 673 square kilometres and contain 18,743,000,000 cubic metres (1). Between it and the Nile valley lie 30 kilometres of desert, of which 11 kilometres are occupied by a marked depression discovered by Liernur Bey in 1887. At the extreme western edge of the Nile valley, which is here some 20 kilometres wide, flows the Bahr Yusuf, and the extreme eastern edge the Nile. It is proposed to put the Nile in communication with the Wady Rayan by means of an inlet canal for filling the reservoir and an outlet canal for discharging its waters. The inlet and outlet canals are clearly shown on Plate 15, while the longitudinal and cross sections are given on plates 16 *(a)*, 16 *(b)* and 16 *(c)*. The principal masonry works are given on plates 17 and 18.

70. — It may be of interest to compare the area and principal features of the ancient lake Mœris with those of the proposed Wady Rayan reservoir. Allowing for a difference of about 4.50 metres between the levels of the Nile valley in B. C. 2,000 and to-day (2) it may be assumed that R. L. 22.50 was the high water mark of lake Mœris (3), and the area 2,500 square kilometres, against 673 square kilometres of the Wady Rayan at R. L. 27. The ancient lake enjoyed this great advantage that in those days the Bahr Yusuf was an important branch of the Nile, if not the main river itself (4) and the reservoir was connected with the Nile by a natural ravine of great breadth and insignificant length, across which a massive embankment was thrown. The surplus of high floods was stored for the deficiency of low *floods*, and by cutting the embankment at the right moment a wave was sent down the river which insured the irrigation

(1) See Appendix X. Table I.
(2) See Appendix III, pages 5 and 6.
(3) The Fayoum and lake Mœris, by Major R. H. Brown, page 79. London, 1892.
(4) See Ptolemy's map of Egypt.

of the Delta just as the opening of the great Kushesha escape does to-day. The renewal of this earthen bank was a matter of such importance that its cost figured in the accounts of the Pharaohs. The Wady Rayan reservoir on the other hand will have to be connected with the Nile by means of a narrow artificial canal of over 50 kilometres in length and will have to supply a small constant supply for four months to increase the discharge of the Nile in *summer*. A comparison between lake Mœris and the proposed Wady Rayan reservoir is like that between Macedon and Monmouth.

71. — The longitudinal sections (plate 16) give an exact idea of the different strata cut through by the canals. The Nile valley itself along the line of the inlet canal consists of a solid deposit of hard clay of from 6 to 10 metres in thickness lying on coarse sand. Along the line of the outlet canal we have alternating strata of sandy clay and clay to a depth of 10 metres. Between these lines lie the ruins of Ahnessa (Herakliopolis) the ancient capital of the island Nome of Egypt. The island has to-day disappeared, but the sandy character of the strata bears witness to the increased velocity given here to the Nile flood by the draw of lake Mœris. The gradual disappearance of the lake was accompanied by the gradual silting up of the western channel of the Nile. The soil along the outlet canal is inferior to that ordinarily met with in Egypt and the spring level is in places near the surface. As this canal will run with a severe velocity, I have allowed in the estimates for pitching its bed and slopes. On leaving the Nile valley and entering the deserts, we meet with sand at the surface or sand conglomerate with gypsum and salt, and then a yellow marl with Epsom salts and finally a bitter plastic clay of a black colour overlying the Parisian limestone. The clays and marls are most extensive in the narrow neck of land between the Nile valley and the Fayoum and for a distance of some 10 kilometres south of it. They rise to a height of 70 metres above sea level. There are none of these marls inside the Wady Rayan or in the depressions connected with it, but as they have to be traversed by the canals, they constitute a very serious factor in the question of the Wady Rayan reservoir. They are extraordinarily easily dissolved in water, and it is on their account that I have chosen the alignment of the inlet canal along the Bahr Bilama where we have only 2,500 metres of them instead of along the alternative line marked on the plan where we have no less than 9 kilometres. No embankment could in my opinion be constructed of these salty marls and bitter clays which could hold up water for any length of time. Where the canal cuts through them, I have lined the bed on slopes with coarse rubble masonry so as to keep the water from ever coming in contact with them.

Geological.

72. — A narrow neck of land, some 15 kilometres in length, runs between the Fayoum and the depressions traversed by the Wady Rayan canal. This neck of land is in continuation of the salty marls and clays; but the limestone is

near the surface and is overlaid with a thin skin of sand and pebbles. It looks like the beach of the ancient sea which once covered the Fayoum. Its northern slope is covered with Nile corbicula shells at a level of about 22.50 metres above mean sea, while the plain at its foot contains strata of compact fresh water shells. The southern slopes are devoid of fresh water remains of anykind. It is evident from this that the ancient lake Mœris which covered the Fayoum rose to a level of about 22.50 metres above mean sea, while the Wady Rayan has never had Nile water in it. The limestone in Wady Rayan and neighbouring depressions is inferior to that at the Tura quarries and is strewn thick with nummulites (principally the nummulitus Gizehensis). It is covered in places with rich deposits of gypsum and salt. Long lines of sand hills traverse the deserts as well as the Garak basin of the Fayoum. These hills may give a little trouble in the future at the places where they cross the canal as the sand flies in volumes along them whenever there is a strong wind.

Supply and discharge

73. — The Wady Rayan reservoir might be fed from the Nile or the Bahr Yusuf or from both, while it must discharge into the Nile. The Nile in flood runs so frequently at a level below that needed for flood irrigation that, if the reservoir were to depend on what it could obtain in flood, it would be unable to discharge an appreciable quantity of water in three years out of ten. If reference is made to table 6 of Appendix III, it will be seen that 1873, 1877, 1880, 1882, 1884, 1888 and 1893 were years in which the flood practically failed to attain a gauge of 6.30 metres at Cairo, which is the minimum needed for effective flood irrigation and that consequently in those years the reservoir would have failed. The remodelling of the basin feeders recently carried out by Col. Ross has also resulted in a lowering of the Cairo gauge by 30 centimetres during the flood. Under these circumstances, it is as necessary for the Wady Rayan to draw its supply of water in winter (when there is never any deficiency) as it was necessary for the Nubian reservoirs. The natural source of supply in winter is the Bahr Yusuf and, if there were no question of filling the Wady Rayan between R. L. — 42 and R. L. + 24, we might dispense with an inlet canal for the Nile. The inlet canal will however be needed to raise the level of the reservoir to R. L. 24 and make it ready to receive the top film of 3 metres which alone can be effectively discharged. In years of high flood, however, this canal will be of use and will be capable of lowering the level of the Nile by 15 centimetres. The quantity is apparently insignificant, but in times of flood every little tells. The Bahr Yusuf takes its supply from the Ibrahimia Canal which has its head at Assiout. The Bahr could be made to discharge 200 cubic metres per second and by just within its banks in winter if a weir were constructed across the Nile downstream of the Ibrahimia canal head. It has long been in contemplation to construct this weir for the sake of improving the irrigation of Upper Egypt quite independently of the Wady

Rayan. Its cost might fairly be debited to the irrigation of Egypt and not to the Wady Rayan reservoir [1]. I have prepared plans and estimates for this work, but as it has nothing to do with the reservoir project, I shall do no more that assume its existence. Without a weir at Assiout, I see no way of insuring the filling of the Wady Rayan reservoir every year. The Bahr Yusuf could not carry more than 260 cubic metres per second in winter without hurting the lands on its banks and, for a similar reason, the Wady Rayan reservoir cannot be maintained at a level above R. L. 27 without permanently injuring large tracts of country [2]. The navigation of the Nile between Assiout and Cairo in low years would be considerably affected by the withdrawal of this large quantity of water in March, but the navigation north of Assiout is not of much importance compared with that to the south, and this point may be overlooked. Of the 260 cubic metres per second carried by the Bahr Yusuf, about 60 cubic metres per second will be needed for the irrigation of the Fayoum and other improved tracts leaving 200 cubic metres per second (or 17.000,000 cubic metres per day) for the reservoir. By this means we shall insure the filling to the reservoir *every year* to its full level of 27 metres above sea level. This is a matter of the greatest importance. Reservoirs which can only insure a good discharge after high floods when the supply in the Nile itself is abundant, and which fail after low floods when the Nile is most in need of water, are not worthy of serious consideration.

74. — I propose giving both the inlet and outlet canals a bed width of 40 metres. The inlet canal will have a slope of $\frac{1}{20,000}$ and the outlet of $\frac{1}{10,000}$. Table 3 of Appendix X gives the discharges of these canals with different depths of water. During flood I find that canals of the ordinary widths and depths of Egyptian canals which run with a velocity greater than .80 metres per second silt as readily as those which run less than .50 metres per second; I propose therefore that in high flood the inlet canal shall run perpetually with a depth of 6 metres, a velocity of about 80 centimetres per second and a discharge of 230 cubic metres per second. In winter, as already stated, the Bahr Yusuf will supply 200 cubic metres per second. That will be from the 1st December to the 1st April. During November there will be half supply as that is the time of "Sarf" or discharge of water and the drying of the lands all over Upper Egypt. This will be as necessary when summer irrigation is introduced as it is to-day. Table I of Appendix X gives the areas and contents of the Wady Rayan reservoir at different levels. Table II of Appendix X gives the flood gauges of the Nile at the head of the inlet canal. The evaporation will be 2.50 metres per Supply.

(1) To enable the Ibrahimiah Canal to discharge this extra water for the Wady Rayan the Nile weir would have to hold up 4.5 metres of water as against 3.0 metres for ordinary irrigation.

(2) See some very pertinent remarks on this subject in "L'irrigation en Égypte" by J. Barois, page 19, Paris, 1887.

annum, and will be taken in the calculation as 2 metres in one year and 3 metres in the next. With these facts before us, we may calculate the time it would take to bring the reservoir up to R. L. 27.00, assuming that we began to fill in 1873-74.

230 cubic metres per second = 20,000,000 cubic metres per day.
200 » » » » = 17,000,000 » » » »

1873-74 — No supply in flood.
In winter 135 days × 17,000,000 = 2,300 millions.
The lake would rise to — 16.00 and owing to evaporation would be at .... — 19

1874-75 — In flood 90 days × 20,000,000 = 1,800 millions.
In winter 135 days × 17,000,000 = 2,300 »

Total..... 4,100 »

The lake would rise to — 1 — 2 = — 3
1875-76 like 1874-75. — The lake would rise to + 9 — 3 = + 6
1876-77 like 1874-75. — The lake would rise to + 16 — 2 = + 14
1877-78 like 1873-74. — The lake would rise to + 19 — 3 = + 16
1878-79 like 1874-75. — The lake would rise to + 23 — 2 = + 21
1879-80 like 1874-75. — The lake would rise to + 27 .... = + 27

In seven years the reservoir would be in working order. As we shall see in the next paragraph, it will be necessary for the reservoir to have its levels raised annually from R. L. 24 to R. L. 27. This means 2,000,000,000 cubic metres of water. During years of low flood, the whole of this supply must come from the Bahr Yusuf in winter which, as we have already seen, is capable of discharging 2,300,000,000 cubic metres. During flood the daily evaporation off the lake will be (650,000,000 × .008) 60 cubic metres per second, which can be spared from the Bahr Yusuf so as to maintain through the flood the level of the reservoir at a constant level.

Discharge.

75. — We now come to the discharge from the Wady Rayan reservoir. In the matter of discharge this reservoir is handicapped as compared to the Nubian reservoirs. It could supply a heavy discharge in May, but owing to the decreasing head, less in June and still less in July; while, as we can see from paragraph 18, we want much more water in July than in May. The Nubian reservoirs having their sluices above the summer level of the Nile can discharge much or little as required; and, besides this, in a good summer they could keep their water and discharge it all in 15 days at the beginning of the flood and so immensely improve the maize crop by allowing it to be sown early. The water from the Nubian reservoirs might be utilised in Upper or Lower Egypt, while that from the Wady Rayan reservoir could only be utilised in Lower Egypt. In years of very low supply, the discharge of the Nile falls to 160 cubic metres

per second north of Assiout and, if 100 cubic metres per second were withdrawn from this at Assiout for the Upper Egypt canals, it would be made good by the outlet canal of the reservoir north of Beni Suef. This would leave only 60 cubic metres per second in the Nile between Assiout and Beni Suef and would affect most seriously the health as well as the irrigation of Upper Egypt.

76. — The head of the outlet canal is removed 12 kilometres from the downstream end of the deep cutting of the inlet canal, and though I have widened the cuttings at kilometres 46 and 56 in order to minimise the fall back from the reservoir, we may assume that there will always be a fall of .40 metres between the reservoir and the head of the outlet canal, when the latter is acting. Therefore on the 1st of April when the reservoir begins to discharge, the R.L. of water surface will be 26.60. The evaporation will be 8 millimetres per day or .25 metres per month. Referring to table 3 Appendix X, it will be seen that: —

At R.L.	24.00	the depth of water will be	m.3.00	& max:discharge	91	c.m.p^{r}second			
»	25.00	»	»	»	» 4.00	»	173	»	»
»	26.00	»	»	»	» 5.00	»	240	»	»
»	27.00	»	»	»	» 6.00	»	326	»	»

In April the canal will begin with its water surface at........ R. L. 26.60

The discharge will be 25 cubic metres per second, and with the evaporation, the level at the end of April will be R. L. 26.35

The discharge in May will be 105 cubic metres per second or 270,000,000 cubic metres and with the evaporation will reduce the level to........................ R. L. 25.60

The discharge in June will be 125 cubic metres per second or 330,000,000 cubic metres and with the evaporation will reduce the level to:........................ R. L. 24.85

The discharge in July will be 125 cubic metres per second and by the end of July the level of W. S. will be.... R. L. 24.00

The outlet canal could therefore discharge 125 cubic metres per second (11,000,000 cubic metres per day) through June and July. To obtain a discharge of 20,000,000 cubic metres per day (230 cubic metres per second) through July, it would be necessary to lower the bed of the Inlet canal from kilometre 20 to kilometre 24 by 2 metres, to lower the floors of two of the regulators at the Bahr Yusuf crossing and the whole 31 kilometres of the outlet canal. This would add to the cost of the works, but that is a small consideration. It would, I think, increase so considerably the liability of the banks of the canal slipping in during the summer and reducing the section that we should have no real gain from the great depth. During my first two years service on the canals in the Delta, I often saw the very deep canals almost choked up with serious slips, and it was not until the level of the water surface was raised at the Barrage, and, with it, the beds of the canals, that we were free from this danger. I consider

the bed level of the outlet canal as low as any canal ought to be in similar soil. especially when it cuts clean across the drainage of the country with the right bank along its entire length a kind of sub soil drainage escape.

Inlet and Outlet canals.

77. — I propose making the head of the inlet canal a little to the south of Biba and taking the canal at an L. of 45° across the Nile valley. The Bahr Yusuf is crossed at the 13th kilometre, but it will be diverted as shown on the plan, and cross the canal at its 20th kilometre near the edge of the desert. At the Bahr Yusuf crossing will be also the head of the outlet canal from the reservoir. which will have a general direction at right angles to the inlet canal and reach the Nile just to the north of Bûsh. From its 20th kilometre to its tail at the 58th kilometre, the inlet canal will also act as an outlet canal. In the clay of the Nile valley, the canals will have a bed width of 40 metres and side slopes of 1 to 1 $\frac{1}{2}$. At the 24th kilometre of the inlet canal, there will be a vertical drop of 4 metres, as we are here on rock (1). The bed will be reduced from 40 metres to 25 metres since it is warranted by the discharging capacity of the section. On plate 16 (*a*) are given the cross sections it is proposed to give in the different soils. In the clays and sands below high water mark, I have given slopes of 1 vertical to 1 $\frac{1}{2}$ horizontal; but above high water mark, 4 vertical to 1 horizontal. This latter slope is very steep, but is the only one possible if the estimates are to be kept down. I have chosen R. L. 21 as the bed of the inlet canal at its 20th kilometre and this fixes the levels everywhere else. It is quite useless having a canal with its bed below the level of the loose sand which underlies the clay and this loose sand is met with at R. L. 21 along the western part of the Nile valley. Occasionally borings have disclosed it at 3 and 4 metres below soil, but they were quite local. The outlet canal as before stated will be pitched. It has a slope of $\frac{1}{10,000}$ against $\frac{1}{20,000}$ in all the other canals. The alternative inlet canal crosses 9 kilometres of the salty and bitter marls and is at such a low level in great part of the Nile valley that it would compromise the cultivation on some 6,000 acres and I cannot recommend it (2).

Masonry works.

78. — The masonry works will be: —

1. Regulating Head to the inlet canal (plate 18).
2. Regulating Tail to the outlet canal (plate 18).
3. Bahr Yusuf crossing and outlet canal head (plate 17).
4. Ibrahimiah canal Syphon and Railway bridge on the inlet canal .... } Exactly similar to those or the Rayah Tewfiki.
5. D° D° outlet canal .... }

(1) I agree with Col. Western that a drop of 4 metres may be given here. A greater drop and still further contraction does not commend itself at the canal will often be used to bring the reservoir up to full supply level during floods when the water will be laden with silt.

(2) At the end of Appendix X is the estimated cost of this canal.

The works will be founded entirely on sand and quicksand and I have chosen the foundations of the Rayah Tewfiki Head (page 16 Appendix II) as a type. As the head of water will be very considerable and of long duration the floor has been made everywhere 3.50 metres thick. This is all the more necessary as it is proposed to use Egyptian mortar largely in place of Portland cement. The masonry will be of the type usually employed in the country. The cost of works for allowing the basin floods to cross both the canals would have been so excessive that it has been decided to allow the tract of 36,000 acres between the two canals to be irrigated in summer from the Ibrahimia. This will effect a considerable saving. The Bahr Yusuf regulator has been provided with a lock as the canal is navigable. No locks have been provided for the reservoir canals.

79. — The work would take 3 years to carry out and the reservoir would take 7 years to be filled after the canals were completed, provided the Assiout weir were in existence. The reservoir would supply 125 cubic metres per second as a maximum in July or altogether 1,000,000,000 cubic metres per annum. The cost of the work would be as follows (see Appendix X). **Financial.**

Excavation inlet canals	L.E.	1,321,670
» outlet canal	»	436,640
Masonry works	»	327,000
Masonry living to inlet canal	»	43,750
Pitching outlet canal	»	90,000
Diversion of Bahr Yusuf	»	72,000
Closing depressions into Fayoum	»	1,200
Land	»	60,000
Contingencies 10 °/₀	»	235,226
GRAND TOTAL	L.E.	2,587,000

80. — It will readily be seen that the Wady Rayan reservoir project, if carried out on ordinary lines, would be far too expensive, and it becomes necessary to modify it. Advantage may be taken of the fact that the inlet canal will only be used in high flood (when the Nile valley easily commands the Wady Rayân), and during the raising of the reservoir level from — 42 to + 24. After that the Bahr Yusuf will suffice. The outlet canal too will not be needed till after the reservoir is full and there is no longer any necessity for the inlet canal. A few kilometres to the north of Beni Suêf there is a point on the Nile where the mean low water level is 21.50 and the high flood level 29.60. Here we have a point on the Nile 25 kilometres away from the 20th kilometre of the old inlet canal where we can build either an inlet head or an outlet tail. I propose constructing the inlet canal along this line and digging it with its head at

R. L. 22.25 and slope of $\frac{1}{20,000}$ into the Wadi Rayan, and using it as an inlet canal for 7 years. After the seventh year it will be deepened on a slope of $\frac{1}{10,000}$ backwards into the Nile and act as an outlet canal only. The R. L. of the bed at the tail will be 18.50 and that will be the level of the floor of the regulating work. By this means we shall save as follows: —

+ Cost of the old inlet and outlet canals in clay L.E. 715,600		
— Cost of the new inlet and outlet canal combined » 379,200		
Saving in earthwork...........	L.E.	336,400
Saving in Land........ L.E. 60,000 — L.E. 28,000 =	»	32,000
» on Bahr Yusuf diversion......................	»	72,000
» » Masonry works.........................	»	80,000
» » Minor works............................	»	22,000
	L.E.	542,400
Contingencies.............	»	54,200
TOTAL SAVING...	L.E.	597,000

The new inlet and outlet canal combined is drawn on the Plan of the Wady Rayan (plate XV). Deducting this saving from the total expenditure of L. E. 2,587,000, it will be seen that the Wady Rayan reservoir works could be constructed for L.E. 1,990,000 (1), while the reservoir would discharge 1,000,000 cubic metres, with a maximum in July of 125 cubic metres per second. To make the canal capable of discharging 20,000,000 cubic metres per day or 230 cubic metres per second in July it would be necessary to lower the level of the canal bed by 2 metres. As the bed is already 3.0 metres below the mean low water level of the Nile, I think it fruitless to try and make it deeper. I am sure there would be ceaseless landslips which might not only make the extra depth profitless, but even close the canal for upwards of a week at a critical time of the year and seriously compromise the rice crop of Egypt. I estimate the cost of deepening the canal 2 metres as follows: —

Earthwork 3,120,000 at 4/—........................	L.E.	124,800
Pitching 600,000 at 15/—..........................	»	90,000
Additional cost to masonry works....................	»	15,000
Contingencies..............	»	23,000
TOTAL.......	L.E.	253,000

I cannot however recommend this expenditure. A canal running *across* the Nile valley with its bed 5 metres below summer level of the Nile could not be maintained.

In making the estimates for the works connected with this project, I have allowed very low rates as I believe that the large quantity of work to be done

(1) This reservoir canal will be able to relieve high floods by acting as an escape to the Bahr Yusuf.

will permit of it. I have not however allowed for scouring out the salty marls and bitter clays by the force of the current itself after a narrow channel has been dug through the hill. Such a channel might choke itself up and cause the loss of a year; while we all know that the water can either run full bore and fill the reservoir in seven years or spend much of its time in cutting away the clay and lengthen out the time of the filling of the reservoir. As the interest charges on the work will amount to L.E. 100,000 per annum, I think it safest and best to execute the works completely as fast as possible and get the reservoir into working order at the earliest date.

81. — It was stated in para. 9 of this report that Lower Egypt possessed 1,200,000 acres of land capable of reclamation, but lying at present as swamps and salted plains. In my book on Egyptian Irrigation and again in my report on Reservoirs (1), I proposed utilising many of the low depressions as reservoirs, notably lake Edku in Behera. Since writing I have had no time to make any detailed surveys of these works and can add nothing to what I then said. Further reading has convinced me of their practicability. I may refer here to "Hydraulique Agricole" by De Cessigny, pages 53 to 55, Paris 1889; to "Rivières et Canaux" by P. Guillemain, vol. I, pages 230-232, Paris 1885; and "Les Irrigations" by A. Ronna, vol. I, pages 276, 463, 472, &c., Paris 1889. Mr. Lang Anderson, the manager of the lake Abukir Reclamation Company, has long studied the question of washing salted land in the Nile valley and placed the results of his experiments at my disposal. They confirm my previous impressions. When once the reclamation of the low lands has really begun, the value of these reservoirs, scattered among the lands themselves and directly available, will be appreciated. Meanwhile we may omit them, as they are inexpensive works and within the powers of the Irrigation Department to carry out on its own initiative. **Basin reservoirs.**

82. — I have now considered all the reservoirs which it is possible to construct in Egypt, and have attempted to deal impartially with all the projects, treating each one when it was before me just as though there were no other reservoirs sites in the country. It remains now to compare the different projects with one another. On pages 23 and 24, I have described the low level reservoir proposed for the head of the 1st Cataract while, on plates 8 and 9, I have given general and detailed plans. As levels have disclosed parts of Philæ temple so low that no reservoir of any kind, high or low, could be constructed at the cataract without putting some part of the temple under water, the low level reservoir labours under the same disadvantages as the high level ones and is much less economical. I have therefore, in Appendix VIII, made out the cost of constructing **The different reservoir projects compared.**

(1) "Egyptian Irrigation", page 137. Nile Reservoirs", pages 43, 45 and 69.

high level dams at the cataract and find that, if the water surface were raised to R. L. 115 metres, the reservoir would contain 2,900,000,000 cubic metres and cost L. E. 1,370,000, of which L. E. 350,000 would be for compensation. The evaporation would cause a loss of water of between 5 and 7 per cent. If the water surface were raised to R. L. 118, the reservoir would contain 3,900,000,000 cubic metres and cost L. E. 1,660,000, of which L. E. 550,000 would be for compensation. We may now compare the different schemes :—

		Water available in cubic metres per annum.	Cost.	Cubic metres per L.E. 1.
1. Assuân cataract reservoir.......	R.L. 115	2,700,000,000	L E. 1,400,000	1,900
2. » » »	R.L. 118	3,700,000,000	» 1,700,000	2,100
3. Kalabsha reservoir..	R.L. 115	1,800,000,000	» 1,300,000	1,400
4. » »	R.L. 118	2,560,000,000	» 1,600,000	1,600
5. Assuân cataract reservoir..	R.L. 105	900,000,000	» 800,000	1,100
6. Gebel Silsila reservoir...	R.L. 100	2,390,000,000	» 1,600,000	1,500
7. » » »	R.L. 104	3,510,000,000	» 1,900,000	1,800
8. Wady Rayan reservoir.........	R.L. 27	1,000,000,000	» 2,000,000	500
9. Philæ reservoir................	R.L. 115	2,650,000,000	» 1,800,000	1,300
10. » »	R.L. 118	3.580,000,000	» 2.100,000	1,700

We can see from para. 19 that the amounts of water needed are :—

Lower Egypt	1,500,000,000	cubic metres per annum.
Upper Egypt north of Assiout......	950,000,000	» »
Upper Egypt south of Assiout......	1,160,000,000	» »
Total.....	3,610.000,000	cubic metres per annum.

I have placed the different reservoirs in their order of excellence. The Assuân and Kalabsha reservoir at R. L. 118 would be as safe and sound as at R. L. 115, but the raising of the water surface above R. L. 115 inundates the rich villages to the south of Korosko, and as they form a kind of oasis in Nubia, I think they ought not to be disturbed. The Gebel Silsila reservoirs will inundate the town of Assuân. The cost of the Cataract reservoirs are comparatively speaking so low that we might add from L. E. 200,000 to L. E. 300,000 to the estimates for the removal of Philæ Temple to a commanding site on one of the numerous islands at the 1st Cataract well above the reach of inundation. During the execution of the Tiber improvement works at Rome, I saw the engineers dismantling and putting together stone by stone, exactly as it was before, an important masonry bridge of large span, which dated from the time of the Republic and was an object of the most cherished regard. They were preparing to treat the St-Angelo bridge in the same way. At the First Cataract we have " Bigeh " island admirably suited for the site of a temple and well above the high water level of the reservoir.

83. — In comparing the different projects, we may say that, at the Assuân cataract, we have sound rock with the river broken up into a number of shallow streams. At Kalabsha, the rock is sound and the river flows in three channels, but one of them is deep. At Silsila, the rock is inferior, but the depth of water in the single channel which exists to-day is small as the deep channel of the river has silted up. South of Philæ, the rock is sound everywhere except at the right flank where schists have taken the place of granite and where the river is very deep. The Wady Rayan reservoir is inelastic like all reservoirs which charge at the top instead of at the bottom.

Cost of water storage in Egypt compared with Spain and Algeria.

84. — When we compare the cost of water storage in Egypt with what it is in Spain and Algeria, we can clearly see the great advantages which Egypt enjoys. Referring to Appendix I, it will be seen that reservoirs which store from 300 to 400 cubic metres of water per L. E. 1 of expenditure are readily constructed in either Spain or Algeria, while in Egypt we estimate that we can store from 1500 to 2000 cubic metres for the same money. The plentiful supply of the Nile in winter is also another factor which tells greatly in favour of Egypt. Owing to it, there exists no necessity for interfering with the muddy waters of the Nile flood, and we are saved considerable anxiety on the score of silt, an anxiety which is ever present in both the other countries.

IV. — The effect on the magnitude and duration of the floods of a substitution of perennial irrigation for the present system of intermittent irrigation.

This inquiry effects the irrigation system of Upper Egypt only.

85. — We have now to consider the effect of the introduction of perennial irrigation on the regime of the Nile. The perfection of the perennial irrigation of the Delta north of Cairo will in no way effect the Nile in flood. The canals will continue to run as they do at present, and the question of water storage for Lower Egypt is therefore quite independent of the subject of flood protection. In Upper Egypt, however, we have 1,460,000 acres of basin irrigation ; and as each acre receives in a low flood 80 cubic metres of water per day, in an ordinary flood 130 cubic metres per day, and in an extraordinary flood 170 (1) cubic metres per day, while the demands of perennial irrigation are only 25 cubic metres per acre per day, it will readily be understood that we are dealing with a quantity of water which demands the greatest attention.

(1) These figures are found as follows: — Take the discharges opposite the low, mean, and high flood gauges in Table VII, Appendix III; subtract from them 200 cubic metres per second for the perennial canals, and divide the remainder by 1,460,000.

The elements of the problem.

86. — To foretell with exactitude the anticipated changes in the regime of the Nile, it is necessary to know first the daily gauges of the Nile at Assuân and Cairo for a period of at least twenty years, and the discharges corresponding to these gauges. The difference between these discharges represent the consumption of water. We have next to determine the amount of water which passes into the canals, the amount utilised in filling up the trough of the Nile(1) and covering the berms, and the amounts evaporated and absorbed. We know that the last three items are constant while the canal discharges are variable and depend on the system of irrigation and, if our data are correct, we can tell with certainty what changes in the level of the Nile will follow certain changes in the system of irrigation.

Gauge records.

87. — Table VI of Appendix III contains the Assuân and Cairo gauges for a period of twenty years from 1873 to 1892, and the mean gauges of these twenty years. Finding it impossible to understand the Nile without first referring every gauge to some uniform standard, I had to choose the line of reference. The mean high water level and the mean low water level were both available(2). In Egypt the mean high water level varies very considerably whether we take it in August and the early part of September when the basin canals are running full supply, or in the latter half of September when the canals are running only half supply, or in October when the basins are discharging back into the Nile. Early and quick rising floods have a different series of levels from slow and late floods; while again the recent works carried out in Upper Egypt by Col. Ross have so increased the discharging capacity of the canals that the flood gauges have been appreciably affected. All this points to the conclusion that the mean high flood is no satisfactory standard. The mean low flood on the other hand is much less liable to change and is very fairly constant from year to year. High floods are certainly followed by scouring out of the bed, and low floods by a silting up of the channel, but the changes are very moderate compared to those in high flood. I have chosen the mean low water level as the line of reference, and all gauges mentioned in this report are referred to it. From the mean of twenty years observations, this level was found to be at Assuân R. L. 85 metres. By observations along the Nile generally, and by calculations at Cairo, I have fixed it at all important places north of Assuân. Table IX of Appendix III gives the Reduced Levels at different places, while it is also drawn on the longitudinal and cross sections of the Nile in plates XIX and XX. It was on this system that the ancient Egyptian Engineers worked the Nile. They however chose the mean high water level during the early part of the flood as their standard of reference and consequently made the so called cubits in the

(1) « *Le irrigationi nell'Egitto* » by Prof. J. Benetti, page 27, Rome 1892.
(2) « *Guida del idrologia fluciale* », page 58, by Lombardini, Milan 1870.

flood reaches of the Cairo gauge half cubits. This means a discharge of 1600 (1) cubic metres per second and fairly represents the discharges of the basin canals in flood. When it is considered that the level of the Nile valley is raised by about 12 or 13 centimetres per 100 years it will be seen that the old Cairo gauge, which was a living record 1500 years ago, is to-day a meaningless anachronism. It has also to be compared with the Assuân gauge which was erected in Ismael Pasha's time with an arbitrary zero some 90 centimetres below mean low water level, and which may be reading 17 cubits while Cairo may be recording 25 cubits. The Cairo gauges in winter and summer are no records of discharge as the afflux from the Barrage affects them. To find the discharge at Cairo during these months, I have added those of the Rosetta and Damietta branches and the Delta canals upstream of the Barrage. When the Nile falls below mean low water level, the gauges are recorded as minus quantities.

88. — Discharge sites having been chosen for the Assuân, Assiout and Cairo gauges on the Nile, a continuous series of surface velocity observations, cross sections and slope measurements were made during 1892 and 1893 and the resulting discharges (2) recorded on plate XXVII. Curves of discharge were drawn and referred to the gauges of twenty years and modified until finally a curve was found which suited any year whether it were a maximum or a minimum. In connection with this subject, it must be remembered that the Nile bed is raised by silt during low floods and scoured out during high floods and that consequently August and September discharges very considerably at times from October and November discharges for the same gauge. In addition to this, it must also be borne in mind that the slope of water surface and that consequently the discharge of a flood during the rise is far greater than during the fall for the same gauge. Indeed the Nile often discharges more when it is 30 centimetres below its maximum and rising fast than when it has reached its maximum and begun to fall. It is owing to this fact that we often see the discrepancy of the Assuân gauge reaching its maximum a day before Halfa which is 360 kilometres higher up the river. The discharge depends on gauge and slope, and the gauge only records one element. Keeping these facts in my mind, I saw that it was of no use recording the gauges to two places of decimals and covering paper with useless figures, and consequently I chose the higher unit for a rising gauge and the lower for a falling gauge when I was dealing with discharges. Table I of Appendix III contains the discharges, while Table II gives five daily gauges and discharges at Assuân, Assiout and Cairo for 1892 and 1893. Through the **Discharges.**

(1) The half pics run from 5.2 to 6.8 on the Cairo gauge and 1.60 metres at the top of the mean flood gauges of the Nile represent a discharge of 3200 cubic metres per second.
(2) For the Nile discharges by surface velocity observations, Harlacher's method has been employed with a constant of .85. For discharges calculated from slope, Manning's formula has been used with a constant of 40.

courtesy of the Inspectors General of irrigation, flood discharges were taken of all the canals in Upper Egypt through 1892 and 1893 and have been recorded in tables IV and V of Appendix III. From these tables, table VII has been compiled which gives rough approximate discharges of the canals corresponding to the Assuân gauges in the first half of the flood.

The trough of the Nile, evaporation and absorption.

89. — To obtain information about the trough of the Nile, the area exposed to evaporation and the area of absorption, a longitudinal section of the Nile from Assuân to Cairo has been levelled, and cross sections taken at every 3 kilometres. Plates XIX and XX give these sections while tables XI and XII of Appendix III give the mean results. The kilometrage on the plan and sections of the Nile counts from the Assuân gauge and is measured down the centre of discharge of the flood, since it is with flood discharges that we are principally dealing. As the Nile winds about considerably and is often broken into numerous channels, the areas of the cross sections vary very appreciably according as they are taken at right angles to the centre line of discharge or of the deep channel of the river. The former gives the more reliable results. I have taken 8 millimetres per day as the evaporation during flood in Upper Egypt (1). The absorption has been calculated from the water consumption during the floods of 1892 and 1893, and found to be about 300 cubic metres per second between Assuân and Assiout, where there is practically no perennial irrigation. Between Assiout and Cairo, where there is a considerable length of perennial irrigation on one bank and limestone rock on the other, the absorption is about 100 cubic metres per second.

Appendix III.

90. — Appendix III contains a monograph on the Nile which, with its tables, embodies all the above information, and will be referred to on all points connected with the enquiry before us.

Effect of the change of irrigation on the regime of the Nile.

91. — When perennial irrigation has once established itself in Upper Egypt, we may assume that the absorption during flood will be halved in quantity for the reasons given in para: 89, and become 150 cubic metres per second between Assuân and Assiout, and 50 cubic metres per second between Assiout and Cairo. The amount of water expended in irrigation will be, according to para: 16 of this report, 700 cubic metres per second. The evaporation during flood will be approximately 120 cubic metres per second (see table XIII of Appendix III). The quantity of water needed to fill the trough of the Nile will depend on the gauges and may be calculated from table XII of Appendix III. The last item will be the only variable one and the others may be approximately tabulated as follows: —

(1) « Egyptian Irrigation », page 27; where it is stated that Linant Pasha considered it as 9 millimetres per day, and observations on Lake Kurûn made it 7 1/2 millimetres per day in May and June.

Expenditure of water in flood in cubic metres per second:

	Between Assuan and Assiout.	Between Assiout and Cairo.	Total.
Perennial irrigation........	350	350	700
Evaporation..............	65	55	120
Absorption...............	150	50	200
Total of above...	565	455	1020

Taking these quantities and calculating directly for the filling of the trough from the gauges themselves, I have collected in table XVIII of Appendix III the Cairo gauges corresponding to the Assuân gauges for the high years 1874, 1878 and 1892, and the minimum year 1877. As far as the more important results are concerned, I tabulate them here: —

Gauges at Assuân and Cairo.

Date	1874			1878			1892			1877		
	Assuan	Cairo with basin irrigation	Cairo with perennial irrigation	Assuan	Cairo with basin irrigation	Cairo with perennial irrigation	Assuan	Cairo with basin irrigation	Cairo with perennial irrigation	Assuan	Cairo with basin irrigation	Cairo with perennial irrigation
August.... 5	6.9	..	..	5.6	..	..	6.3	..	..	4.9	..	..
10	7.4	6.5	5.8	5.3	4.9	4.4	6.8	5.3	5.1	5.4	4.0	3.9
15	8.5	6.9	6.4	7.2	5.4	5.2	6.7	5.8	5.8	5.8	4.7	4.6
20	8.6	7.3	7.8	7.5	6.0	6.3	7.4	5.4	6.2	6.4	4.6	5.0
25	8.7	7.5	7.9	8.1	6.3	6.5	8.3	5.8	6.5	6.1	5.3	5.5
31	8.7	7.6	8.1	7 6	6.6	7.2	8.3	6.6	7.7	6 2	5.3	5.6
September 5	9.0	7.7	8.2	8.1	6.5	7.5	8.6	6.9	7.7	6.3	5.2	5.2
10	8.8	8.0	8.3	8.5	6.8	7.5	8.8	7.1	8.0	6.1	5.3	5.3
15	8.7	8.2	8.4	8.9	7.2	8.0	8.8	7.5	8.3	6.0	5.2	5.5
20	8.4	8.3	8.5	8.9	7.6	8.5	8.9	7.9	8.3	6.0	5.2	5.4
25	8.4	8.4	8.2	9.0	7.9	8.5	8.6	8.1	8.4	6.3	5.1	5.4
30	8.2	8.4	8.2	9.1	8.2	8.5	8.4	8.3	8.4	6.1	5.3	5.6
October.... 5	7.9	8.7	7.9	8.9	8.4	8.6	8.2	8.4	8.3	5.6	5.2	5.4
10	7.6	8.5	7.6	8.5	8.7*	8.6	7.8	8.3	8.1	5.2	5.0	5.0
15	7.2	8.3	7.4	7.9	8.4	8.4	7.4	8.1	7.7	4.9	4.9	4.6
20	6.6	8.0	7.0	7.6	8.1	8.0	7.2	7.9	7.2	4.6	4.6	4.4
25	6.2	7.7	6.3	7.4	7.9	7.4	6.8	7.9	7.0	4.5	4.4	4.0
31	5.6	7.0	5.9	6.8	7.7	7.2	6.3	7.8	6.6	4.0	4.2	3.9

* (The Nile breached its banks on the 10th October 1878 and thus prevented any further rise of the gauge).

To enable one to compare these figures with the gauges as recorded at present, I add the following table: —

ASSUAN						CAIRO					
Real gauge in metres	Gauge as recorded in cubits and 24ths		Real gauge in metres	Gauge as recorded in cubits and 24ths		Real gauge in metres	Gauge as recorded in cubits and 24ths		Real gauge in metres	Gauge as recorded in cubits and 24ths	
	Cubits.	24ths.		Cubits.	24ths.		Cubits.	24ths.		Cubits.	24ths.
0.0	1	13	5.0	10	20	0.0	6	9	5.0	15	19
.5	2	12	.5	11	18	.5	7	7	.5	17	12
1.0	3	10	6.0	12	16	1.0	8	5	6.0	19	8
.5	4	8	.5	13	14	.5	9	4	.5	21	4
2.0	5	6	7.0	14	12	2.0	10	2	7.0	22	12
.5	6	4	.5	15	11	.5	11	0	.5	23	10
3.0	7	3	8.0	16	9	3.0	12	0	8.0	24	9
.5	8	1	.5	17	7	.5	13	0	.5	25	7
4.0	8	23	9.0	18	5	4.0	13	23	9.0	26	5
.5	9	21				.5	14	21			

16 cubits at Assuân corresponds to 7.8 metres.
17 » » » » » 8.3 »
18 » » » » » 8.9 »

16 cubits at Cairo corresponds to 5.1 metres.
22 » » » » » 6.7 »
23 » » » » » 7.3 »
24 » » » » » 7.8 »
25 » » » » » 8.3 »
$25^1/_2$ » » » » » 8.6 »

92. — The flood of 1874 was an early one and the basins were discharged on a falling Nile, still they raised the Cairo gauge to 8.7 metres on the 5th October, while it would have risen to 8.5 on the 15th September with perennial irrigation. The flood of 1878 was an exceedingly late one and the basins had to be discharged while the river was still very high. By the 10th October, the river had risen to 8.7 metres at Cairo when the banks were breached and all future rise stopped. With perennial irrigation, the maximum gauge of 8.6 metres would have been reached on the 10th October. The flood of 1892 was at Assuân 10 centimetres below that of 1874 and 20 centimetres below that of 1878, and midway between them in point of time. It was also under complete control owing to the new regulating works on the basins. It rose to 8.4 metres at Cairo on the 5th October and fell exceedingly slowly. With perennial irrigation, it would have risen to 8.4 at Cairo on the 30th September and then fallen rapidly. These results are plotted on plate XXVIII and the comparative rate of rise and fall can be easily studied on the diagrams.

93. — Speaking generally, we may say that with perennial irrigation the very high floods at Cairo will be 15 days in advance of what they are at present, that they will not rise higher, and that they will fall 15 days earlier than what they do now. With low floods there will be no appreciable difference as to date, but there will be a slightly higher gauge at Cairo. In ordinary floods, there will be an advance of from 20 to 25 days in the date of the maximum flood and a maximum gauge at Cairo 50 or 60 centimetres under the maximum gauge at Assuân. We have so far considered Cairo only, as the Delta proper depends on the Cairo gauge. We now turn to the Nile in Upper Egypt itself: South of Sohag, there will be no serious change in levels, but the Sohagia and Ibrahimia canals between them carry at present 750 cubic metres per second in excess of what they would carry if there were perennial irrigation in Egypt, and the greater part of this water is not returned to the Nile until the Kushesha escape is reached. The reach of the Nile from Sohag to Kushesha is the one which will experience the greatest changes, and I calculate that there will be a rise of 40 centimetres as compared with the maximum gauges under basin irrigation. **Summary.**

V. — The best method of controlling the floods and the cost of the undertaking.

94. — We have seen that, if basin irrigation were replaced by perennial irrigation, the Nile at Cairo in an exceptional year like 1878 would rise to a height of 8.6 metres, and this would be 20 centimetres above the maximum gauge of 1892. Judging from the experience of basin irrigation in 1878 and 1892, we may say that, with the basins under complete control as they are at present, a flood like that of 1878, with its maximum of 9.1 metres at Assuân on the 1st October, would under present conditions rise at Cairo to a height not under 8.6 metres. The flood of 1874 attained a level of 8.7 metres at Cairo and traversed the two branches of the Nile without causing a breach until within 60 kilometres of the sea. This flood came early and the basins were discharged quickly so that the banks had no time to become sodden and dangerous; and it is owing to this that, in my opinion, there was so little damage done in 1874. As, with perennial irrigation, the floods will rise and fall quickly, we may contemplate the Nile in the Delta without much anxiety. The banks to-day are in far better order than what they were 20 years ago, and we have besides spent L. E. 500,000 since 1882 in providing 800 kilometres of banks with spurs and protective works. A further expenditure of L. E. 300,000 would complete the works and change anxiety into responsibility as far as the Nile banks were concerned. An expenditure of L. E. 800,000 for 800 kilometres of bank means L. E. 1,000 per kilometre, and this may be taken as the cost of Nile protection. **The Rosetta and Damietta Branches of the Nile.**

95. — The Rosetta branch has a far greater carrying capacity than the Damietta branch. After the great breach near Cairo in 1878, the former carried the whole of the water which escaped from the breach as well as its own natural discharge and rose 1 metre above its normal height. It was then at the same height above the country that the Damietta branch normally is. When there is no basin irrigation and no direct discharge back from the basins into the Rosetta branch, it will be possible to take full advantage of this fact. Turning the Bahr Yusuf into a drainage cut as proposed by Major Brown, and continuing it along the foot of the desert hills as far as the Barrage, it will be possible to divert into this branch 300 cubic metres per second of drainage water and relieve the Damietta branch of this quantity. Mr. Foster contemplates making an escape direct from the main Nile into the Rosetta branch at its 12th kilometre.

96. — With the Rosetta branch always available for the escape of flood water, and an expenditure of L. E. 300,000 to perfect the protection of the banks, we may say that, as far as Lower Egypt is concerned, the basin irrigation of Upper Egypt may be changed into perennial irrigation without causing more anxiety than what exists to-day. The change from one system of irrigation to the other must of necessity be gradual (1), and experience will teach us how far our anticipations have been justified. New facts and new data will enable us to modify our calculations and gradually perfect the system of perennial irrigation without running any risks.

The Nile in Upper Egypt.

97. — We saw in para. 93 that a rise of 40 centimetres was contemplated between Sohag and Kushesha on the introduction of perennial irrigation into Upper Egypt. If Upper Egypt north of Assiout is alone taken in hand, the rise will be halved. To protect the country against flood the 400 kilometres of bank between Assiout and Kushesha should be provided with spurs at a cost of L. E. 400,000. To this may be added L. E. 50,000 for raising the banks. The total cost of protection would be therefore L. E. 450,000. When however we consider the fact that a breach of the Nile bank would be attended with far more serious consequences in a perennially irrigated tract than in one under basin irrigation, it would be a decided relief to the country if the Nile in flood could be controlled before it entered Egypt. There are two places where this might be done. One is Kaibar or Hannek, the other is probably Dâl.

(1) "*Nile Reservoirs*", page 49, Cairo, 1891. When we consider that the Ibrahimia canal with its basin feeders discharges in flood 2100 cubic metres per acre while the Sohagia and other canals discharge 6300 cubic metres, we can see that it will be possible to make a beginning by reducing the area under basin irrigation on the Ibrahimia canal by 66 per cent without interfering with its discharge.

98. — If reference is made to plate I, it will be seen that upstream of the Hannek Cataract on the left bank of the Nile(1), is the great El Kâb depression, which is considered to be lower than the Nile valley. The Hannek and Kaibar Cataracts were surveyed and levelled by de Gottberg in 1857(2). On plate I, I have reproduced de Gottberg's plans and sections of Kaibar, and it will be seen that there we have a site wonderfully suited for a regulating work. Sir John Fowler's engineers, on their way to Khartoum from Wady Halfa, passed by the Hannek Cataract ; by combining their levels of the railway line, Sir B. Baker's levels of the Nile, and de Gottberg's sections, it becomes evident that a raising of the flood water surface at Kaibar by about 8 metres would enable us to control the Nile in flood by discharging its surplus water into the deserts. The Hannek Cataract is not so wonderfully suited for a dam as Kaibar, but a raising of the water surface in flood by 2 metres would suffice to control the Nile. Here then we have two sites where in all probability at a cost of L. E. 700,000 (I assume a rate for work 100 per cent in excess of that at Assuân) we should have absolute control of a high flood and be enabled to send down the Nile the quantity of water which we deemed sufficient for irrigation. It is possible that there is an opening from the Nile to the Selima wells from above the Dâl Cataract as is so frequently stated by travellers, and as the Dâl Cataract is granite, we might be able to construct a regulating weir there ; but we have no reliable information on this point. The Nile in Nubia.

99. — In order to insure the country against floods we must, either strengthen the banks of the Nile at a cost of L. E. 750,000 [Lower Egypt L. E. 300,000 and Upper Egypt L. E. 450,000], or we must control the Nile in flood before it enters Egypt. I personally consider the latter method of protection as infinitely the better and the more reliable. If we were able to prevent a flood from rising above 8.0 metres at Assuân, we should save in a year like 1874, 1878, 1887 or 1892 a very considerable area(3) of maize from inundation by direct drowning or infiltration water along 1300 kilometres of the Nile, we should prevent deterioration of land along the banks of the Nile and the destruction of villages in Upper Egypt, and enormously relieve the burden of flood protection which is none the less heavy because it does not figure in the Government accounts. I think I may place at L. E. 200,000 per annum the gain to the country from any work which could effectively control the Nile in flood in both Upper and Lower Egypt. Conclusion.

(1) Appendix III.
(2) *Des Cataractes de Hannek et Kaybar*, by E. de Gottberg. Paris 1867.
(3) During a very high flood, a large area is flooded before it is sown and is thus prevented from producing the valuable maize crops.

VI. — The effect on the quality of the water when the new changes are introduced.

The Nubian reservoirs.

100. — The Nubian reservoirs will be filled in November and December after a low flood, and in December and January after a high flood. At this time of the year the Nile water is very pure, and as it will be perpetually flowing with a depth of from 10 to 30 metres, it will consequently remain pure. The effect of this quantity of wholesome water on the green water of the Nile in June and July of a low summer will be to dilute it and considerably improve it. The Nubian deserts are quite free from impure and harmful salts of all kinds. The numbers of reservoirs in the world which store water and which have stored it for hundreds of years, without in any way hurting it, are a perfect guarantee for any reservoirs constructed in the bed of the Nile.

The Wady Rayan reservoir.

101. — The question of the Wady Rayan reservoir becoming brackish was discussed at a meeting of Khedivial Geographical Society at Cairo on the 16th March 1888(1). Col. Ross was of opinion that it would not be brackish while Dr Schweinfurth feared it might. Since that discussion took place, very extensive series of borings have been made. These borings have disclosed strata of salt but the bitter marls and salty clays which could have contaminated the water have nowhere been found inside the Wady Rayan or the Wady Liernur(2). Considering the enormous quantity of water which would be discharged into the lake as compared to the amount of salt, I cannot conceive how the lake could become brackish. I share Col. Ross' opinion.

Cairo, 25th November, 1893.

W. WILLCOCKS,
Director General of Reservoirs.

(1) " Egyptian irrigation ", page 317.
(2) See Dr. Schweinfurth's note in Appendix XIII, where he considers that the water will not be brackish, but that in all probability there will be serious losses from leakage.

APPENDIX I.

DESCRIPTIONS OF EXISTING RESERVOIRS

Epitome of

« Annali di agricultura 1886

Laghi artificiali dell'Algeria, della Francia e del Belgio »

And

« Annali di agricultura 1888

Irrigazioni e laghi artificiali della Spagna »

BY

GIUSEPPE ZOPPI E GIACOMO TORRICELLI.

Cairo, 1892.

« Annali di agricultura 1886. — Laghi artificiali dell'Algeria, della Francia e del Belgio ».

« Annali di agricultura 1888. — Irrigazioni e laghi artificiali della Spagna ».

Relazioni degli ingegneri GIUSEPPE ZOPPI e GIACOMO TORRICELLI.

The summing up of these Italian Engineers is contained in the following sentences.

1. — « All the Spanish dams, ancient as well as modern, have been constructed on the hardest rocks, generally granite or limestone. We think that it is owing to this that they are absolutely stable. To reach the solid rock, the Spanish Engineer at Puentes, did not hesitate to take the foundations of that dam to a depth of 24 metres below the bed of the stream so that, from the bottom of the foundation to the crest of the dam, that work is 72 metres high. Comparing the dams we have seen in Algeria with those we saw in Spain, we are convinced that no high dams should ever be built on any rock except that which in exceedingly hard, and in which especially there is no trace of marl or clay ». (*)

2. — « The problem of the prevention of the silting up of reservoirs has not yet been solved. It depends on the nature of the soil and the slope of the reservoir, and the Spanish system which has succeeded perfectly in some reservoirs, is not universally applicable ».

I now proceed to the Epitome of the two works.

Hydrological, geological, and agricultural observations on Algeria.

Practically all the rivers in Algeria are torrents with considerable floods during the rainy season and scarcely any water in summer. The water in the rivers is always muddy as though it came from recent showers and not from springs. The drought in summer is excessive. The Tell is the name given to the region which drains into the Mediterranean and it is with this tract only that we have do. It is bounded on the South by the Atlas mountains which rise in places to a height of 2500 metres above sea level.

Western Algeria has no forest to speak of, and the catchment basins of the streams are generally dry and barren, formed principally of a clayey marl, which under the action of water melts rapidly away. The streams have a slope of $\frac{1}{350}$ and over, and their waters are very heavily charged with mud. The rainfall varies from 30 centimetres to 1 metre per annum, with mean of 40 centimetres. Nearly all the rain falls in the winter. The rainfall is steadily decreasing owing to the very rapid destruction of what remains of the forests. The destruction of the forests is due to: — forest fires, animals feeding in the forests, manufacture of charcoal, and the conversion of forest into cultivated land.

The greater part of the rainfall is evaporated and very little sinks into the hills since there are practically no springs. The rivers carry off a very small proportion of the total rainfall; thus the Cheliff carries $\frac{1}{30}$, the Habra $\frac{1}{60}$, the Sig $\frac{1}{60}$, while small streams like the Thelat may carry $\frac{1}{15}$. The largest river in Algeria, the Cheliff, has a discharge in summer of 2 cubic metres per second, while the Habra has only $\frac{1}{2}$ a cubic metre per second, the Sig and the Mina have an insignificant discharge, and all the rest are dry in summer.

(*) The engineers elsewhere consider 20 metres as the maximum height of dam permissible on rocks which contain clay strata. By 20 metres height of dam, I understand them to mean 20 metres head of water. They however are strongly opposed to dams of any kind on rocks containing traces of marl or clay.

It is for this reason that there is a demand for reservoirs capable of storing water in winter, and discharging it in summer. The summer crops are cotton, maize, flax, sesame, tobacco, vines, gardens and meadows. Cotton is sown in March and gathered in November. The cotton is generally sown every second year, as one year's roots do for two years.

Cotton is irrigated for 5 months from May to September, receiving 10 irrigations of $6\frac{1}{2}$ centimetres each, or altogether 2700 cubic metres per feddan or acre. The amount of water allowed is 17 cubic metres per acre per day. In Egypt 22 cubic metres per acre per day are provided in the canals, though the fields ordinarily receive 17 cubic metres per acre per day.

Of course, with such little water as they have in Algeria, the system of irrigation is delicate and complicated, and nothing is to be learnt from it of any practical value to Egypt.

In describing the different reservoirs, I shall follow the two Italian Engineers, in dividing the subject into 7 heads: —

1. General. — 2. Geological. — 3. Profile of the dam and the composition of the masonry and method of construction. — 4. Irrigation sluices. — 5. Under sluices. — 6. Waste weirs, and 7 Financial.

Reservoir dam on the Khamis River.

1. General. This dam is situated about 40 kilometres S. E. of the town of Algeirs. Begun in 1869, and interfered with by the Franco-German war, it was completed in 1884. It is 38 metres high, 40 metres long at base, and 162 metres long at top. The width at top is 5 metres and at base 27.8 metres.

The capacity of the reservoir is 13,000,000 cubic metres. The total rainfall of the small catchment basin is 700,000,000 cubic metres, of this $\frac{1}{50}$ will suffice to fill the reservoir.

There is no loss from filtration.

The daily loss by evaporation in summer is 10 millimetres per day or 1.50 metres in 5 months. This loss is made up by the discharge of the stream.

2. Geological. The rocks at the source of the stream are alternating strata of clay and sandstone of the cretaceous period, and lower down the valley the same sandstone followed by Nummulite limestone. Under the sandstone appears at the site of the dam an outcrop of mica schists. The dam was built partly on mica schists and partly on sandstone. The mica schists are impervious to the water, the sandstone is porous with many faults on the downstream side of the dam. But as the dip of the strata is 40° and inclined towards the upstream of the dam the infiltrations are not serious.

The dam might have been entirely constructed on mica schists, but in order to secure a slight economy it was built partly on the sandstone. As soon as the reservoir was filled, the right wing of the dam, which is on the sandstone, moved away from the rest of the dam and the reservoir was quickly emptied through the undersluice. A strong retaining wall is being built to support the part which has cracked. All this would have been avoided if the whole dam had been built on the mica schists at a slightly greater original cost.

3. Profile of the dam, and masonry. The weight of the masonry in calculation has been taken at 2200 kilograms per cubic metre and the weight of the water 1000 kilograms. Considering the amount of mud suspended in the water in the flood, when the reservoir is full, the Italian Engineers consider 1100 kilograms as a safer weight per cubic metre of water.

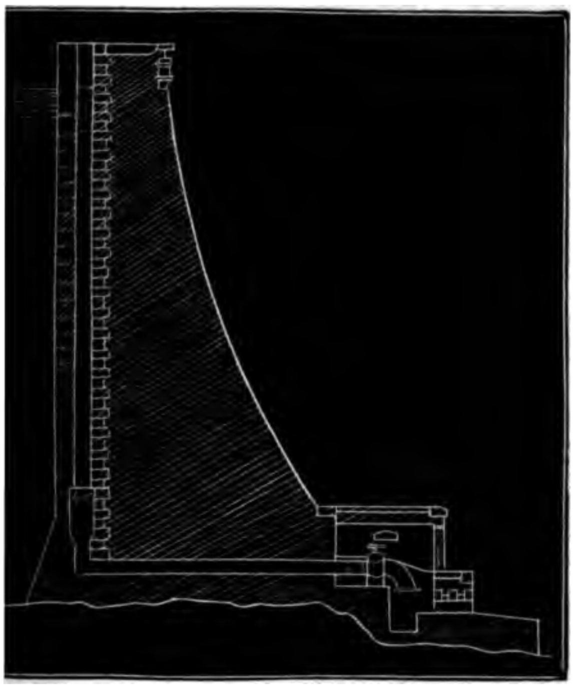
Taking 1000 kilograms as the weight of a cubic metre of water, the Italian Engineers calculate that the maximum pressure on the masonry on the downstream side is 11 kilograms per square centimetre; and a tension of 2.7 kilograms per square centimetre on the upstream side, which is bad.

The dam in plan is straight and not curved.

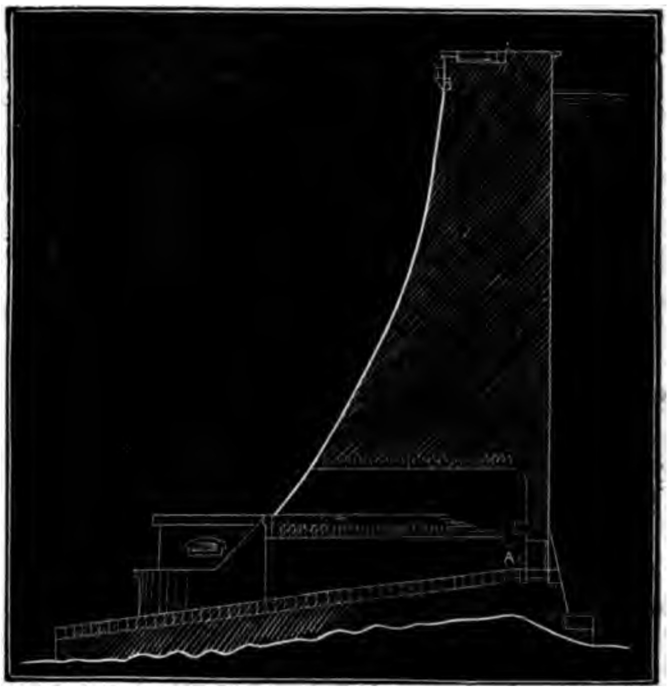
The mortar was made of Theil lime from France and sand in the proportion of 350 kilograms of lime to 1 cubic metre of mortar. The class of masonry is uncoursed rubble. The sluices are lined with ashlar. The stone used in construction was a rather inferior sandstone.

4. Irrigation sluice.

The irrigation sluices in the Algerian dams are all made on the pattern of the Spanish sluices which have worked well for centuries. Each sluice consists of one or more cast iron pipes of from 50 centimetres to 1 metre diameter laid horizontally across the dam near its foundation course and opening on their upstream side into a vertical well which is left in the body of the dam near its upstream face. This well is generally about 1 metre broad and some 4 metres long, and is of the same depth as the height of the dam. The thin masonry wall between the reservoir and the well is pierced with numerous holes of about 30 centimetres diameter each all the way from the bottom to the top, so that whatever may be the depth of deposit in the reservoir a certain number of holes is always open to the water. The cast iron horizontal pipes project beyond the downstream face of the dam, and are provided with regulating values. They discharge their water into a tank from which it flows into the irrigation canal.



(Figure 1). IRRIGATION SLUICE.

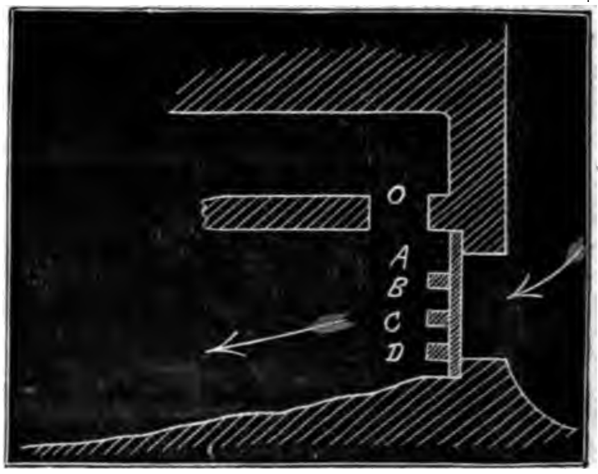


(Figure 2). UNDER SLUICE.

5. Under sluice.

In the Khamis dam, the two cast iron pipes are each 86 centimetres in diameter, and the canal is calculated to discharge 1 cubic metre per second.

The undersluice at Khamis is on the Spanish principle. It is situated at the bottom in the line of the bed of the original stream. A Spanish undersluice consists of an opening of from 1 to 3 metres in height and from 1 to 2 metres in width at the upstream end; it increases gradually as it advances downstream until at the downstream end it is sometimes so much as 4 metres wide and 6 metres high. This opening is closed at the upstream end by a wooden door, called a Spanish door, supported against wooden horizontal timbers let into apertures in the two sides at the point A in figure (2). Just above the undersluice is a gallery. This gallery is about a metre wide and 2 metres high and is closed on the upstream side and open on the downstream face to allow workmen to enter. It communicates with the undersluice by an opening some 60 centimetres in diameter just downstream of the gate A (figure 2).



(Figure 3).

The door is put in position in the undersluice from the downstream side when the reservoir is empty, and the three horizontal timbers B, C, D (figure 3) are let into slots in the jambs, and the whole door is well caulked. The water now rises in the reservoir and as the deposits accumulate, they bury the door and gradually gain great consistency. It takes 4 years for the deposit to become solid, though it is generally left 10 years. When the reservoir has got filled up with deposits to the extent which is considered a maximum, the workmen enter the undersluice, bore with an augur through the door to be sure that the mud is solid, saw the timbers B, C and D, and then escape into the gallery. The door is not free to drop, but is generally held by the solidified mud. The workmen now go to the top of the dam and work a hole through the deposit with a long iron pole until the water touches the door. When this happens, the door falls and the mud follows it in a tremendous avalanche. The reservoir is soon emptied and more or less of the deposit removed. A new gate is then put in, new horizontals B, C, D are placed behind it, and the reservoir begins to fill again.

In the Khamis dam there are two of these scouring sluices 13 metres apart. They are each $1.20^m \times 2^m$ at the upstream end and 2.50×5.0^m at the downstream end. One large opening would have been more effective. The water rushing through these sluices has attained a velocity of 15 metres per second.

As the reservoir has not really worked yet, no estimate can be formed of their power to remove deposit.

6. Waste weir. The waste weir has been cut out of the solid rock. It has a width of 30 metres. The rock is not good enough for a waste weir to be safe.

7. Financial. As the lime of the country was not used, but expensive lime was brought from France the masonry cost L. E. 1 per cubic metre instead of L.E. 0.60 per cubic metre, as it otherwise would. The work was constructed by Government and cost altogether, with its canals, L. E. 120,000. As the amount of water stored is only 13,000,000 cubic metres, it comes to L. E. 1 per 100 cubic metres which is very costly.

The dam is being repaired.

The Habra dam.

1. General. This dam is situated about 70 kilometres S. E. of Oran. It was begun in 1865 and completed in 1871. The height of the dam (exclusive of foundations) is 36 metres, the length at base 100 metres and at crest 325 metres. The width at top is 4.30 metres and at the base 27 metres. The reservoir has a capacity of 30,000,000 cubic metres and supplies 3 cubic metres per second. The catchment basin is 8000 square kilometres and the capacity of the reservoir is $\frac{1}{90}$ of the rainfall. The loss by evaporation is 10 millimetres daily in Summer.

2. Geological. The rock at the site of the dam is formed of alternate layers of clay and sandstone of the Miocene formation. It was originally intended to construct it a little upstream of its present site on clay schists of the upper cretaceous formation, but it has actually been built on sandstone. The clay is soapy and expands when wet, while the sandstone is fissured. There are moreover numerous faults. The reservoir was filled in 1871 and there were serious leaks which

discharged 20 litres per second. These leaks ran continuously till 1881 when the right flank of the dam yielded and the reservoir emptied itself through the rent thus made. The cause of the failure of the dam lay in the alternating layers of sandstone and clay. The right flank of the dam which fell is not straight, but inclined at an ∠ of 110° to the rest of the dam. The rupture began at the ∠ which was really faulty for a structure of this kind. The water of the dam, working its way under great pressure for 10 years through some stratum of clay, thoroughly liquified it, carried it away, undermined the work and caused the accident. At the time of failure, there was only an extreme compression of 4.70 kilograms per square centimetre, and an extreme tension of 0.50 kilograms per square centimetre.

The company is repairing the damage by building a new deep wall in continuation of the main part of the dam.

4. Profile of the dam and masonry. With the exception of the right flank wall which leaves the main dam at an ∠, the dam is straight and not curved. The maximum pressure is 6 kilograms per square centimetre. The sandstone of which the dam is built is inferior. The lime was burnt on the spot.

The irrigation sluices are ordinary.

5. Under sluices. There are two scouring sluices, each $1^m.20 \times 2.^m0$ at the upstream end and $1.^m50 \times 4.^m0$ at the downstream end, capable of discharging 30 cubic metres per second.

The sluices are regulated by wrought iron gates put in motion by a vertical iron shaft worked by a screw at the top of the dam. It takes 5 $\frac{1}{2}$ hours to open one gate. This delay is fatal to the scouring power of the gates, and the undersluices have not been a success.

7. Financial. The dam cost L. E. 120,000, and as the water contained in the reservoir was 30,000,000 cubic metres, the cost of the water was L. E. 1 per 250 cubic metres.

The repairs under execution will however cost L. E. 50,000.

The Shurfâs dam.

1. General. This dam is situated about 50 kilometres S. E. of Oran. The height of the dam is 30 metres above the foundation, which is in places 10 metres above the rocky bed of the river. The length at base is 50 metres and at top 155 metre. The width at top is 4 metres and at bottom 22 metres. Begun in 1882 it was completed in 1884. The reservoir was capable of containing 16,000,000 cubic metres.

2. Geological. The dam is founded on alternate strata of marly limestone and clay. The rock is of very inferior quality, some of it being crushed when wet at 11 kilograms per square centimetre. The reservoir was filled in January 1885 and the right bank fell in February of the same year. The inferiority of the rock was the cause of the failure. If the dam had been moved a little upstream, it would have rested on compact stone. It would have cost far more, but it would have been safe.

3. Profile of the dam, and masonry. The maximum pressure allowed was 6 kilograms per square centimetre. The mortar was made with Theil lime from France.

4. Under sluices. There was one Spanish undersluice. It was closed by the ordinary Spanish door, which of course can only be opened when the reservoir is filled with compact deposit. As there was no deposit in the reservoir in February 1885, the door could not be lowered and consequently there was no possibility of opening the undersluices and relieving the dam of pressure when it began to fail.

7. Financial. The dam cost L.E. 33,000 in spite of its small size because the masonry cost L.E. 1.20 per cubic metre. As the water contained in the reservoir was 16,000,000 cubic metres, this would have meant L. E. 1 per 500 cubic metres if the dam had not failed.

The Sig dam.

1. General. This was an old dam constructed in 1845 and raised in 1858. The reservoir had however practically silted up and it was to aid this reservoir that the Shurfâs dam was constructed. When the Shurfâs dam failed, its water bore down on the Sig dam, rose 6 metres over its crest and swept it away too.

2. Geological. The rock here is a compact limestone, and the dam, which was 26 metres high had stood with perfect security for 40 years.

3. Masonry. The lime for the mortar was burnt at site. The composition of the mortar was 1 lime, 2 humra, and 1 sand, and the resulting masonry excellent. The masonry constructed of local lime cost L. E. 80 per cubic metre, with Theil lime L. E. 1.20 per cubic metre, while ashlar work cost L. E. 3.00 per cubic metre.

The Muley Magoun dam.

1. General. This dam is built partly of masonry and partly of earth in contact with each other. The contact has never been established, and the consequence is that the reservoir has never been filled and his practically been abandoned.

Thelat dam.

1. General. The first Thelat dam was constructed of earth in 1860 and swept away in 1862. Its length was 27 metres. The existing dam was built in 1869. It is 21 metres high, 13 metres long at base and 100 at top. The width at top is 4 metres and at base 12.30 metres. It is built on a compact limestone and is absolutely safe. As the dam was provided with an undersluice only $1.0^m \times 1.5^m$, it was incapable of keeping the reservoir clean of deposit, and the reservoir to-day has been completely obliterated. The dam cost L. E. 6,400 and the capacity of the reservoir was 600,000 cubic metres of water, or 100 cubic metres for L. E. 1.

Jedawia dam.

1. General. This masonry dam is 17 metres high and the capacity of the reservoir was 2,000,000 cubic metres. The dam is built on sandstone sufficiently compact with alternate strata of very compact pudding. The rock is strong enough for a dam 17 metres high. The maximum pressure on the foundation is as high as 9.5 kilograms per square centimetre. The undersluice is $1.40^m \times 0.80^m$ and is regulated by a screw gate. The dam cost L. E. 18,000, and therefore the storage cost L. E. 1 per 112 cubic metres of water. The undersluice has been a failure and the reservoir is completely filled up with deposit.

Wady Meurâd dam.

1 General. This is an earthen dam 21 metres high, with a depth of water in the reservoir of 18 metres. The capacity of the reservoir is 900,000 cubic metres. Begun in 1853, it was completed in 1864 and is working to-day.

2. Geological. The rock is basalt and very compact.

3. Profile. Though the dam is only 21 metres high on the upstream side, it is 29 metres high on the dowbstream side, and is probably the highest earthen dam in the world. The width at top is 3.50 metres and at base 90 metres. Its length at top is 110 metres and at base 20 metres.

The up and downstream slopes are 1 vertical to 2 horizontal. It is faced with masonry steps on it upstream side.

The undersluice is a single pipe 80 centimetres diameter. It is insufficient and the deposit is increasing steadily in the reservoir. There is a project for increasing the sige of the sluice. **5. Under sluices.**

The dam and its adjuncts cost L. E. 16,000, and as the capacity of the reservoir is 900,000 cubic metres, this means L. E. 1 per 60 cubic metres. A masonry dam would have been cheaper and safer on such a solid rock foundation. **7. Financial.**

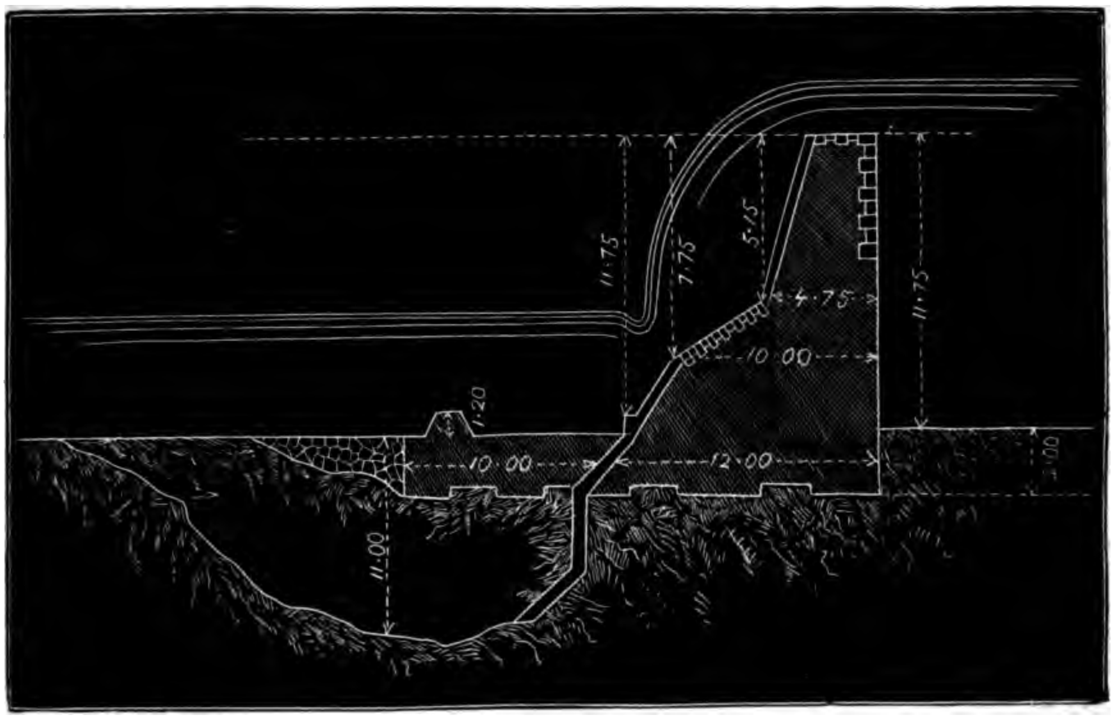
Weir on the River Cheliff.

This work is not for water storage, but for diverting the waters of the Cheliff river into the Orleansville canals. The canals irrigate 30,000 acres. The ordinary summer discharge of the Cheliff is from 3 to 4 cubic metres per second, though occasionally it falls to 1.5 metres per second. The ordinary floods are from 50 to 60 cubic metres per second, though extraordinary floods of 1,500 cubic metres per second have been recorded. **1. General.**

The weir is solid and has its crest 11.75 metres above the bed of river. It is 58 metres long at its bottom and 85 metres long at top. The width at top is 2.50 metres and at bottom 11.80 metres. It is circular in plan with a rise of 5.8 metres on a length of 85 metres.

The rock on which the weir is built consists of alternate layers of sandstone and clay of the miocene formation. It is inferior in quality. The living rock was found at a distance far below that indicated by the borings, as the bed was strewn with huge boulders, whose existence was not suspected till the foundations were exposed. **2. Geological.**

The slope of the river at the site of the weir is $\frac{1}{470}$. Figure 4 gives a section of their weir. **3. Profile of the river and masonry.**



(Figure 4).

It will be noticed that a platform on masonry $10^m \times 2^m$ was constructed to strengthen the toe of the dam. The weir was completed in 1872, and a heavy flood in that year tore away the masonry platform and excavated a deep hole 7 metres below the level of the plat-

form. This hole was filled with large blocks of masonry and the toe protected with a coating of superior masonry. In 1885, a flood rose 3.70 metres over the crest of the dam, washed away the masonry blocks and deepened the hole another 4 metres. Since then, the hole has been left alone and up to the present no further damage has happened.

Principal dams in France.

Furens dam. This dam was constructed between 1861 and 1866. It is 56 metres high and holds up 50 metres of water. The length at bottom is 10 metres and at top 100 metres. It is 3 metres wide at top and 49 at bottom. The plan is circular on a radius of 253 metres. The dam has been built on solid granite, and is in perfect condition to-day.

Pas du Riot. This dam is 34.50 metres high and was built in 1872-78. It is founded on solid granite and is in perfect condition to-day.

Ban. This dam is 46.20 metres high and was built in 1867-70. It is founded on solid granite and is in perfect condition to-day. All the above dams are constructed on streams which carry very little silt.

Ternay. The same may be said of the Ternay dam which is 41 metres high, was finished in 1868 and being founded on granite is in perfect order to-day.

Among numerous examples of interesting dams, the Italian Engineers give particulars of a dam which is constructed of rubble cemented with mud.

The St Christophe dam.

This dam is rectilinear in plan and 180 metres long at top. It is composed of loose rubble 14 metres wide at top with up and downstream slopes of $\frac{1}{1}$. It holds up 20 metres of water. A masonry channel pierced with numerous holes was made to run over the top of the dam and the muddy water carried by the canal leaked through the dam and left its mud behind, gradually cementing up the spaces between the stones. At the same time the muddy water was allowed to rise gradually in the reservoir and flow through the dam causing a further cementing of the stone with mud. Finally a masonry facing 3 metres wide at bottom and .50 metres wide at top was built on the upstream slope, and to-day the dam is watertight and holds up 20 metres of water. The dam is founded on compact limestone.

Gileppe dam in Belgium.

This dam is 47 metres high and holds up 45 metres of water. It is 85 metres long at base and 235 metres long at top, while the width at top is 15 metres and at bottom 66 metres! The design is very faulty. If it had been given a far slenderer section, the pressures on the base would have been far less than what they are. When the reservoir is empty, the pressure on the upstream face is 10.3 kilograms per square centimetre.

It is built on compact sandstone and conglomerate with the strata perfectly *vertical*. There are interposed between the sandstone and conglomerate strata of clay which would have endangered the stability of the dam if they had been horizontal or slightly inclined. Their vertical position renders them harmless.

IRRIGATION AND DAMS IN SPAIN.

The *salty waters* of the Vinalopo stream, which contain chalk and common salt, and which would be hurtful to ordinary vegetation, are beneficial to palms, pomegranates, carobs and olives. The irrigation is given every fortnight in summer. **Notes on irrigation in Spain.**

Rice culture. — The huerta of Jucar produces annually 60,000 acres of rice. The whole of this rice is transplanted. Some 5,000 acres of rice are sown about the middle of March and irrigated through April and May. At the end of May or beginning of June, the rice is transplanted into 60,000 acres of land and very heavily irrigated. It is reaped in the middle of September. The yield is heavy. By sowing in Egypt about the middle of May and transplanting at the beginning of August, and irrigating the rice heavily through the flood, it might be possible to reap the crop at the end of October. If this could be done, the very difficult question of the water supply in the Berea would find a solution.

It is found in Spain that canals which are specially constructed for summer crops, of course also provide water for winter crops, and are a source of profit beyond what they were originally constructed for. In the dry provinces of Spain, land which is provided with water all the year round is considered three times as valuable as land which depends on natural rainfall.

The Almanza dam.

The Almanza dam is the oldest in Spain. It was built shortly before 1586, at the expense of the community benefiting from it. In a rainy year, it irrigates 35,000 acres, and 20,000 acres in a year of drought. The capacity of the reservoir is 3,000,000 cubic metres. **1. General.**

The dam is 21 metres high, 2.90 metres wide at crest and 10.20 metres wide at base. In plan it is curved with a radius of 26 metres.

The rock on which the dam is built is a very compact and hard sandstone, very well suited for a reservoir dam. **2. Geological.**

The under sluice is $1.30^{m} \times 1.50^{m}$. It has not been used for 32 years. Up till then, it had kept the reservoir clear of deposit, but now there are 15 metres of deposit. **5. Under sluice.**

Alicante dam.

Built between 1579 and 1594, it is in splendid working order to-day. The capacity is 5,000,000 cubic metres. Some 16,000 acres of land are irrigated by it. The length is 9 metres at bottom and 58 metres at top. The width at base is 33.70 metres. The height is 42 metres. The designer and builder of this dam was Herreras, the architect of the Escurial palace. **1. General.**

The rock on which the dam is built is a very hard limestone of the Eucene formation. There is no leakage. **2. Geological.**

The maximum pressure on the toe is 11.30 kilograms per square centimetre, while in very high floods it has risen to 16 kilograms per square centimetre. **3. Profile of the dam, etc.**

5. Under sluice. This it the typical Spanish undersluice. It is $2.70^m \times 1.80$ metres at the upstream end and $5.9^m \times 4.0^m$ at the downstream end. The sluice acts perfectly and the reservoir is clear to-day. This is attributed to the narrow and steep section of the reservoir, which aids the water in scourring away the deposits. The dam should be cleared every 4th year if possible. It is generally done every 10th year.

Elché dam.

This dam built 300 years ago on compact limestcne, has a height of 23 metres and is in perfect order to-day. Owing to the undersluice not having been used for 40 years, the reservoir has completely silted up.

Old Puentes dam.

This dam was constructed in 1785/91, and after working for 10 years it fell in 180?. The reservoir had a capacity of 53,000,000 cubic metres. The dam was 50 metres high, 11 metres wide at top and 46 metres wide at base. It was built on compact limestone rock generally, but on a length of some 20 metres it was built on shingle, into which piles had been driven. The water gradually found its way through the compact shingle, and blew a hole under the dam 17 metres wide and 30 metres deep.

New Puentes dam.

1. General. In 1861 it was determined to reconstruct the dam, and again it was decided to build it on the shingle on a wide base. The work was begun in 1881, but Mr. Francesco Prieto, the Engineer on charge, determined to take the foundation down to the solid rock, and having received official sanction, succeeded in his endeavours.

The new dam is 48 metres high, and the depth of water is 46 metres. The width at top is 4 metres and at bottom 39 metres. The length at bottom is 27 metres and at top 80 metres. The plan is a decided curve.

Before the living rock could be reached, the shingle had to be removed to a depth of 24 metres on a width of 20 metres; it was the narrowness of this gorge which constituted the great difficulty, as room had to be found for pumps, for men to work, and for materials to be removed. The stream was, moreover, liable to heavy floods.

As completed to-day the dam is 72 metres high.

2. Geological. The rock on which the dam is built is a compact limestone.

3. Profile of the dam and masonry. The upstream face of the works is 1 metre of cement masonry. The downstream face for 20 metres from the base upwards is made of ashlar from the old dam, and the rest of ordinary dressed stone. The interior masonry is ordinary rubble in mortar composed of:—

$$\left.\begin{array}{l} \frac{2}{3} \text{ fat lime burnt on the spot} \\ \frac{4}{15} \text{ sand} \\ \frac{1}{15} \text{ Portland cement} \end{array}\right\} \text{Moderately hydraulic.}$$

5. Under sluice. The scouring sluices consist of 3 separate tunnels, each $3.2^m \times 1.80^m$. They are regulated by iron gates worked by screw gear from the top of the dam. The sections of the sluices are contracted at the gates and are there only $2^m \times 1.25^m$. The sills are 40 metres below water surface. The Italian engineers do not approve of the system (1). They would

(1) See « Congrès de l'utilisation des eaux fluviales », pages 7 et 8, Paris 1889. This reservoir had silted up 14 metres by 1889.

have preferred one big sluice with a Spanish door. As it frequently happens on these big dams, in 1887, an attempt to open one of the gates resulted in the breaking of the shaft.

The reservoir has a capacity of 40,000,000 cubic metres and cost L. E. 150,000, though the estimate was L. E. 100,000. The water stored has cost L. E. 1 per 270 cubic metres. **6. Financial.**

Villar dam.

This dam was begun in 1869 and completed in 1876. It is circular in plan. The height is 48 metres and the depth of water is 45.5 metres. As there are 3 metres of foundation, the total height of the dam is 51 metres. The width at top is 5.2 metres and at base 46 metres. The reservoir contains 20,000,000 cubic metres of water. **1. General.**

The dam is built on gneiss, of great hardness and compactness. **2. Geological.**

The dam is built of uncoursed rubble masonry with dressed stone faces. The mortar is composed of 8 parts sand, 4 parts fat lime and 1 cement. **3. Masonry.**

There are two sluices. They have a section of 1.08 square metre each, and are expected to discharge 20 cubic metres per second. The sills are at a level of 45 metres below the water surface. Each opening has two gates worked by screw gearing. **5. Under sluice.**

The dam cost L. E. 66,300 and as the capacity of the reservoir is 20,000,000 cubic metres, the water has cost L. E. 1 per 300 metres. **7. Financial.**

Numerous dams were under construction in 1888, among them the Hijàr dam 43 metres high on a compact limestone foundation. There are other dams in Spain which the Engineers did not see, such as: —

The Huesca dam,	20	metres high	and	300	years old.
Val del Inferno,	36	»	and	100	»
Nijar dam.	36	»	and	40	»
Ponte della Oliva,	32	»	and	40	»

In summing up, the Italian Engineers lay great stress on 3 points:

(1) The absolute necessity of having a solid foundation on a rock free from any traces of clay.

(2) The great strength given to a dam by making it curved in plan and not rectilinear.

(3) Providing amply for the discharge of the silt.

W. WILLCOCKS.

APPENDIX II.

REPORT ON REGULATORS.

The plates accompanying this Appendix have not been printed.

REPORT ON REGULATORS.

I propose describing all the typical regalators seen by me in Europe and Egypt and certain typical Indian works. (*)

The variety of existing works in Italy is very great and I have chosen those works which seemed to me either original or good of their kind. The Italian Engineers themselves had no preference for one kind over another as far as I could make out. The regulating apparatus on the Bacchiglione escape and at the head of the Brentelle Canal seemed to me the must deserving of special attention. They are given on plate 4. At the latter regulator we have regulating apparatus of 6 metres span holding up 6 metres of water. **Italian Regulators.**

In France there seemed to be two systems which were specially patronised at the present time and I have described them in plates 8 and 10. They are : (1) Poirée frames with Boulè shutters, and (2) suspended frames with Cameré curtains. **French Regulators.**

In England every system of regulation is overshadowed by Stoney's patent roller gates of which I have given three examples in plates 11 and 12. Since then, Mr. Stoney has erected the 20 metres wide gates at Richmond which I have seen but of which I have not sufficient details to enable me describe them fully. The gates will hold up 3.5 metres of water and in rising will turn round a quadrant and take up their position of rest in a horizontal plane. **English Regulators.**

I have described the typical Egyptian regulators in plates 13 to 17. **Egytian and Indian Regulators.**

Plates 18 to 24 contain drawings of the principal types of Indian regulators. As most of the dams iu India are solid submergible works, the necessity for regulation is more limited than in Egypt and Europe.

Of all the regulating systems I have seen, I consider Stoney's patent roller gates as the best. Their simplicity, ease of working, water tightness and freedom from all entanglements with floating rubbish render them eminently suited for regulating works in Egypt. For the openings in the reservoir dams on the Nile, they are the only gates which could be used on a scale necessary to discharge the Nile in full flood. **Stoney's patent roller gates the best.**

The foundation in Europe are generally simple, as the subsoil is firm in all those places where the big regulators are situated. This makes the regulating works there comparatively cheap. As an example of a good regulating work built on treacherous quicksand, the Rayah Tewfiki Canal Head (plate 14) is to be recommended. **Foundations.**

I have drawn every regulating work to a scale of $\frac{1}{100}$ so that a comparison may be easily made and the range of the works better understood. **Scale of drawings.**

(*) Of the Indian works, I have seen only the Narora and Betwa weirs. The others are taken from Col. Mulins' "Madras irrigation".

The following list gives details of the works described : —

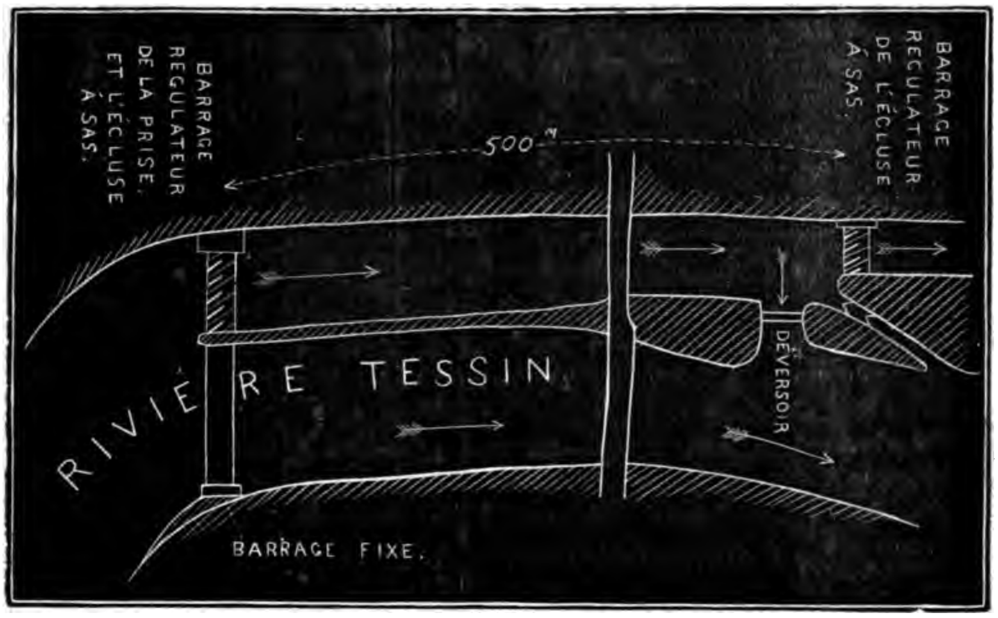
NUMBER OF PLAN	NAME OF WORK	MAXIMUM DEPTH OF WATER IN METRES	MAXIMUM HEAD OF WATER IN METRES	WIDTH OF OPENING IN METRES	COST IN L.E. PER SQUARE METRE OF WATER SURFACE TO TOP OF GATE LEVEL
1	Villoresi Canal Head.......	4.5	4.0	1. 5	
2	San Massimo Canal Head	5.8	2.0	6. 0	
3	Padua Canal Head	6.0	2.0	7. 0	
4	Bacchiglione Escape Head	6.0	2.5	6. 0	
—	Brentelle Canal Head..............	6.0	6.0	6. 0	
5	Padua Canal Regulator............	4.5	2.5	5. 0	
6	Verona Canal Head...............	7.0	7.0	2. 1	
7	Limena undersluice..............	2.2	2.2	8. 0	
8	Suresnes Weir....................	4.6	3.3	72. 0	28.2
10	Poses Weir.......................	5.0	4.0	33. 0	25.3
11	Belleeck Weir....................	4.3	4.3	8. 9	26.0
12	Manchester Ship Canal Regulator...	5.5	5.5	9. 1	
—	» » » ...	7.9	7.9	9. 1	
13	Gangara Regulator................	6.3	3.0	3. 0	8.3
14	Tewfiki Canal Head...............	9.0	4.0	5. 0	16.0
15	Nile Barrage	4.5	4.5	5. 0	22.5
16	Koshesha Escape Regulator........	7.0	4.0	3. 0	14.0
17	Menoufieh Canal Head.............	9.0	3.7	4. 2	2 4
—	Abu Shusha Escape Regulator......	4.5	3.0	3. 0	2.0
18	Dowleshweran Regulator	6.2	3.8	1.83	
19	Bobberlanka Regulator	6.2	3.8	1.83	
20	Tinnevelly Canal Head............	5.3	3.8	1.25	
21	Khannadien » »	5.5	3.6	1. 4	
22	Betwa Canal Head....	11.6	10.0	1.83	30.0
—	» undersluices..............	12.2	8.4	1.83	30.0
23	Narora »	4.0	2.5	2.13	

List of Regulators described.

The following regulators have been described: —

Villoresi Canal Head and Regulator on the Ticino, near Milan (Italy).

These works were constructed by a private company which had a concession from the Italian Government to utilise the supply of the River Ticino, leaving always 120 cubic metres per second in the bed of the river for canals with established rights. The works were begun in January 1882 and completed in April 1884. The works consist of a solid weir across the Ticino, of a regulating Head and Lock for the canal, and 500 metres below these again, of a second regulating head and lock and an escape back into the Ticino with a clear overfall for discharging and measuring the 120 cubic metres per second which have to be returned to the River. Plate 1.



The escape is a clear overfall over a plank floor, and by repeated experiment it has been found that the true formula for discharge is : $Q = \frac{2}{3} \times .684 \sqrt{2gH}$.

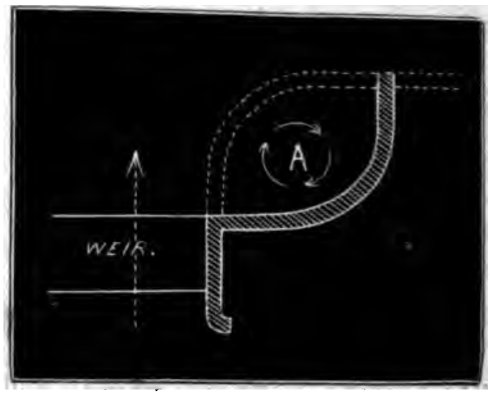
At the site of the work, the water of the Ticino is quite clear as it has just issued from Lake Maggiore. The river is still a torrent with a shingly and boulder bed. The whole of the works are founded on this coarse shingle, which is hard and compact ; the foundations are therefore inexpensive.

The temporary works cost	L.E.	18,000
The permanent training works............	»	18,000
Head and Lock	»	13,000
Solid weir................................	»	23,000

and including contingencies, the whole work cost only L.E. 88,000.

The solid weir is 290 metres in length, 24 metres in width and has its crest 4.75 metres above the bed of the river. The cross section is a double ogee. In flood, the depth of water on the crest is 2 75 metres.

The weir is made of concrete faced with hammer dressed blocks of granite about $.30^m \times .30^m \times .30^m$ with longitudinal and transverse key blocks $2.10^m \times .40^m \times .60$ at intervals, along the crest of the weir. On the down stream ogee, the granite facework is of similar blocks laid between lines of diagonal key stones. 60^m deep; and at an angle 45° to the line of the weir. These stones are clearly shown on plate 1. I saw the work in 1891 after seven floods had passed over it and it was in the most perfect order. On the right bank of the river, the flank wall has been built as in the sketch and consequently there has been a tremendous whirlpool at A which has given great trouble. The construction is now recognized as faulty; it should have followed the dotted lines. All the pitching downstream of the regulator is packed inside galvanised wire nest ("chinfs") of a cylindrical form, three metres long by 2 metres diametre. The meshes are 16 centimetres square and the thickness of the wire 3 millimetres. Each wire net weighed 35 kilogrammes and cost 92 piastres including cost of stone and putting into place.



The pitching was excellent. I thought these wire nets might be used in Egypt with advantage instead of heavy blocks.

The regulating head has a length of 65.60 metres and a breadth of 7.00 metres. The maximum depth of water on the floor is 4.50 metres and the maximum head 2.00 metres, though the regulator is capable of holding up 4.00 metres on an emergency.

The depth of foundation, masonry and concrete is 4.5 metres on the upstream side and 2.0 on the downstream side, with a downstream apron of rubble pitching laid in mortar. Up stream of the regulator, is an 8 metre wide belt of clay puddle overlaid by pitching in mortar. There are 15 arches of 3.40 metres span each, supported on piers one metre wide, 3.10 metres high and 5.0 metres long. The arches support a dead wall 4 metres high running along the entire length of the work. The top of this dead wall is the road way of the Bridge. The cutwaters of the piers are 1.30 metres long and contain two pairs of grooves. Each opening of 3.40 metres width is subdivided into 2 openings of 1.50 metres each by a wall two metres long, .40 metres wide and 3.10 metres high. These dwarf walls support arches and their thin cutwaters have grooves. The sluices are 1.50 metres wide and 3.00 metres high, and there are 30 of them.

The regulation is performed by means of wooden gates moving vertically in the downstream grooves and put in motion by screw lifting apparatus worked from the roadway level of the bridge. The gates are of oak and 12 centimetres thick.

The regulator has worked perfectly ever since it was constructed and is a handsome workmanlike looking structure.

Regulator on the Taglio San Massimo at Padua (Italy).

This is a small regulator with one 6.00 metre wide opening. The maximum depth of water on the upstream side is 5.80 metres and the maximum head is 2.00 metres. The ordinary head of water in high supply is 1.40 metres. The method of regulation is novel rather than worthy of imitation. The work cost L. E. 2,400. **Plate 2.**

An ordinary crane is fixed on one of the abutments and is employed for lowering and raising the horizontal sleepers which are heavy iron I girders, 6.40 metres in length and .30 metre in width. The girders are provided with catches at either end. The "fisher" is a light lattice girder of the same length as the sleepers, and is provided with revolving clips for embracing the catches at either end of the sleepers. If, for instance, a sleeper has to be lowered, the crane raises the fisher and lays it on one of the loose sleepers lying on the abutment. As soon as the fisher rests on the sleeper, the clips revolve a quarter of a circle and embrace the catches of the sleepers. The crane then lifts the sleeper and lowers it gradually into the groove. As soon as the sleeper rests on the floor or on another sleeper, the clip revolves another quarter of a circle and the fisher is freed from the sleeper and can be raised leaving the sleeper in its place. If, for instance, the sleeper has to be raised, the crane raises the fisher and lets it descend between the grooves. As soon as the fisher rests on the sleeper, the clip revolves and embraces the sleeper, and the sleeper can then be raised. All details of the revolving clip are given in plate 2.

I do not think the system a good one, as the fisher has sometimes been prevented from descending to its full depth by the force of the current. The system adopted at the Brentelle head (plate 4) is, I think, infinitely better.

Regulating Head to the Padua Canal. (Canale Maestro) (Italy).

The regulating apparatus is not often used as the Canal is generally open. The regulator has 3 openings of 7 metres width each. The maximum depth of water on the upstream side is 6 metres, and the maximum head 2 metres. The floor is 20 metres wide and 2 metres deep supported on piles. The work is built on good stiff earth. **Plate 3.**

The regulation is performed by cast iron verticals 6.50 metres long $\times$ .085^m $\times$ .075^m, tongued and grooved along their vertical faces which are in contact. These verticals are supported only at the top and bottom, but can be lowered through any depth of water as they are tongued and grooved.

The verticals are raised and lowered by means of a crab travelling on rails on a raised platform.

I do not consider the system worthy of imitation; the verticals are very massive and unmanageable compared with the work they are called on to perform.

Bacchiglione Escape Head near Padua (Italy).

This escape is just above Padua and, on its quick and certain opening in case of a sudden flood, depends the safety of the town. If any accident happened to the regulating apparatus and the escape could not be opened part of the town of Padua would be put under water. The regulating apparatus of this escape is such as to insure certain and speedy opening. **Plate 4.**

The floor platform is 21 metres long, 18 metres wide and 2 metres thick, founded on piles. The downstream apron is heavily pitched and provided with strong cribwork.

The downstream slopes and apron are maintained in perfect order. Indeed the perfect maintenance of the pitching, in all works I saw in Italy, struck me very forcibly whereever I went.

There are three openings of 6 metres width each, with 1.50 metre wide piers between.

The maximum depth of water on the upstream side is 6 metres and the ordinary head 2.50. The cutwaters of the piers are provided with double grooves, of which the upstream grooves are for safety, and in the lower grooves the regulation is performed by cast iron sleepers I in shape, and $.40^{m} \times .40^{m}$ in outside measurement. The sleepers are raised and lowered by means of chains attached to the girders and worked by travelling crabs on a platform at the roadway level. Each opening has a traveller. This traveller, as it lifts each sleeper above the level of the platform, travels to the end of the platform and then deposits the sleeper on the floor. It then returns to its position above the grooves and is ready to raise another sleeper. The sleepers are provided with rollers at either end so as to ensure their not sticking longitudinally in the grooves. The chains are left permanently attached to the sleepers so that, at the time of opening, the sleepers might be readily and without fail taken out. These chains jangle against each other a great deal when in the water and the wear and tear in considerable. They are renewed every four years, which seems expensive; but Mr. Ponti, the Chief Engineer who has practically designed all the important works in the Padua district, considers it better to pay this sum and ran no risks than to have the least uncertainty about the opening of so important an escape.

Regulating Head Brentelle Canal (Italy).

This Canal takes water from the Brenta and feeds the Bacchiglione Canal. During sudden floods it becomes necessary to close this regulator with great rapidity, and on its certain closing the safety of Padua depends. The conditions which prevail here are exactly the opposite of those which prevail at the head of the Bacchiglione Escape.

The regulator has one opening 6 metres wide. The maximum depth of water is 6 metres and in flood the regulator holds up 6 metres of water. The regulation is performed by sleepers or girders 6.80 metres in length of the same section as at the escape head. There are no chains attached to the sleepers; but the sleepers are clips at either end as shown in the perspective drawings attached to plate 4. The sleepers are raised and lowered by means of fishers attached to chains worked by a travelling crab. The fishers keep inside the grooves and clip the girders in a manner similar to that described for San Massimo Regulator. Plate 4 contains details of girders, clips and fishers. These fishers are of various patterns; the one used at the Brentelle Head is the one preferred by Mr. Ponti; it is given in plate 4 and I have a very good moded of it in my office. These fishers and clips can be depended on to lower the girders with certainty, and *close* the regulator; for *opening* the regulator, they are not quite so sure as the attached chains, and it is on this account they have not yet been tried at the Bacchiglione Escape Head, though Mr. Ponti told me he intended employing them shortly.

Regulator on the Bacchiglione Canal in Padua (Italy).

Plate 5. In the very heart of Padua there is a regulator on the Bacchiglione Canal which has some novel features. Mr. Ponti has here tried three systems of regulation side by side.

Each of the openings is 5 metres wide. The upstream depth of water is 4.50 metres and the maximum downstream 2.0 metres, so that the maximum head is 2.50 metres.

Plate 5 gives details of the three systems.

Two openings have a similar method of regulation. In each of these openings, the regulation is performed by an iron gate 4.75 metres high, raised and lowered by two screws, one near each groove. The upper ends of the screws work in a massive overhead iron girder supported by massive iron standards. The power to turn the screws is supplied by handles worked by hand at the bridge roadway level.

One opening has its regulation performed by two horizontal iron gates; the lower gate is 2 metres high and the upper is 3 metres high. To the lower gate is attached a rack worked by a pinion at the roadway level. The upper gate has 4 catches at a level of 1 metre above its bottom. When the lower gate is raised, it rises one metre in height by itself, it then catches the upper gate and both rise together.

A fourth opening is regulated by means of an iron gate 4.75 metres in height, and worked by 3 racks, one near either groove and one in the middle.

Head and tail regulators of the Verona Industrial Canal (Italy).

This canal has been constructed by a private Company in order to obtain power to work cotton and other mills at Verona. The Adige as it winds through Verona has a very rapid fall. By taking a straight canal from the upstream side of the town and dropping it into the river on the downstream side, a head of 9 clear metres at all stages of the river has been obtained and with a uniform discharge of 26.50 metres per second a H. P. of 3000 is guaranteed. Plate 6.

At the take off of the canal, a bar has been thrown across the Adige, which is here a torrent running on a shingly bed. The bar consists of 2 rows of sheet piling 120 metres in length, 3 metres wide and just above low summer level. The space between the piles is filled in with boulders and pebbles. The regulating head is 140 metres down the canal.

The length of the platform of the head regulator is 2.45 metres, made up of 9 openings, each 2.10 metres wide, with piers .70 metres wide between. The piers are 1.60 metres high and support arches carrying a dead wall 2.50 metres wide and 6.20 metres high. The cut-waters of the piers are provided with grooves in which move wooden regulating gates worked by screw lifting gear. These are on the upstream side of the dead wall. On the downstream side of the wall, the openings are regulated by iron gates 2.18 metres wide and 1.90 metres high shaped like the arc of a circle and supported by iron rods radiating from the arc to the centre, where they are attached to iron collars working round cast iron pivots embedded in the masonry of the piers. These circular gates are raised and lowered by chains worked by a hand winch at the roadway level. One gate is practically a safety gate to the other.

The ordinary maximum head of water on the regulators is 7 metres, so that the regulating apparatus is well strained though the openings are small.

The work is founded on stiff shingle which affords a splendid foundation. It is on this account that the thicknes of masonry of the floor is so insignificant.

The tail regulator has a total head of 9 metres of water, but it is broken into 5 falls by masonry steps. The regulating apparatus is called on to hold up 2 metres of water only. The work is almost exactly similar to the head regulator. Besides the two systems of regulation, it is also provided with self regulating apparatus for maintaining a perfectly constant head of water above the tail regulator in that reach of the canal from which the water is taken off to work the turbines.

Limena weir undersluices on the Brenta river (Italy).

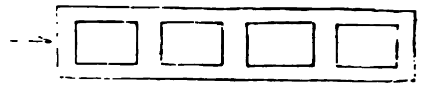
Just downstream of the head of Brentelle canal, there is a weir and lock on the Brenta. Plate 7.

The work consists: — of a solid weir raised 3.20 metres above the bed of the river and 48 metres in length, of an undersluice 8 metres wide with its floor 1 metre above the bed of the river, and of a lock 6 metres wide with its floor at bed level.

The maximum depth of water in flood is 4 metres above the crest of the weir.

The weir is 2.25 metres wide at crest and 13 metres wide at base, nearly vertical on the upstream side and with a slope of $\frac{1}{3}$ on the downstream side.

The upstream edge of the weir is built on rectangular wells each 4 metres $\times$ 12 metres in external measurement with three tie walls thus:



The tie walls are .60 metres thick, and the depth of the wells is 4 metres. The soil is a hard clay.

Downstream of the weir, there are 20 metres width of pitching overlaid by masonry blocks of sizes varying from $2^m \times 2^m \times 1^m$ to $2^m \times 2^m \times .50^m$.

Upstream of the weir, there is a sloping apron of concrete $2^m \times 2^m$.

The upstream platform at the undersluices is 10 metres long and 2 metres deep.

The water, as it leaves the undersluice, has such exceedingly great velocity that it quite deprives to lock of any possibility of being used for navigation and consequently I consider the arrangement faulty and not deserving of being imitated.

The action of the water over the weir is severe, but the slopes have been splendidly pitched for 200 metres in length on either side, and the regulator is in splendid working order.

The regulation at the undersluice is performed in the manner described in Part I of the Report*. This opening is bigger than those described, but the principle is exactly the same. The verticals are $2.50^m \times .10^m \times .10^m$.

This work cost L. E. 30,000 in all.

Suresnes Weir on the River Seine (France).

Plate 8. This work came into operation in April 1885. It consists of three separate weirs and two locks. The locks are on the left bank. Beginning at the right flank, there is first the weir proper 62 metres in length, then an island, then the escape 62 metres in length, then another island, then the navigable pass 72 metres in length, and finally the locks. The two locks are $160^m \times 12^m$ and $60^m \times 8.2^m$ respectively.

The three passes are closed by Poirée frames and gates so that, in high flood, the frames are lowered on the floors which are near the bed level of the river and the river passes freely without any obstruction of any kind.

The floors are not on the same level, but the downstream floor is always 1.00 metre lower than the upstream floor, and the maximum head of water is 3.30. The depths of water during regulation are as follows: —

The weir...........................	Upstream	4.10	Downstream	1,80
The Escape.........................	»	4.10	»	1.80
The Navigable pass.........	»	4.60	»	2.30

The escape is used for ordinary regulation.

As the navigable pass has the lowest floor, it alone will be considered here and alone is given on plate 8.

Referring to the cross section, it will be seen that the floor proper is 15 metres wide and 4.5 metres deep, founded on stiff clay, the upstream apron is 7 metres wide and consists of 3 metres thickness of clay overlaid by 1.50 metres of masonry. The floor upstream of the frames is raised one metre and falls gently to the level of the floor on which the frames rest when they are down. This is the arrangement which, after years of trial and experiment, has been found to be the very best to prevent the clogging of the frames with silt when they are lying on the floor.

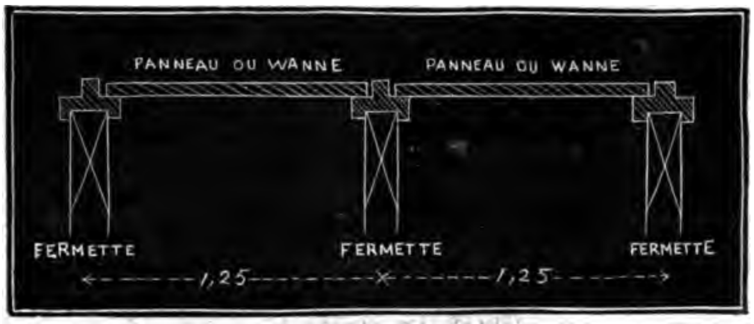
The downstream apron is 10 metres in length.

The moveable parts of the weir consist of Poirée frames and apparatus for regulation.

Frames. — There are 57 frames 1.25 metres apart centre to centre. These frames are braced girders of wrought iron, 2.30 metres wide at top, 4.0 metres wide at bottom and 6.0 metres high, supporting a platform carrying rails. The frames are attached at their

* Not printed.

bottoms to pivots turning in pivot blocks strongly bolted to the floor. These pivots act like hinges, and the frames can be raised by a chain attached to their top either into a vertical position or lowered horizontally on the floor, by means of a powerful crab fixed to one of the abutments. When once the frames are raised and are in a vertical position, they are made tight by tie bars of iron, the rails are connected, and the regulating apparatus is quickly transported from the banks, and the 1.25 metres wide openings between them are closed by means of shutters or curtains whichever the engineer happens to prefer. At the present time, both are being worked side by side to see which gives the best results. The curtains will be described when plate 9 and the Poses weir are being considered. Under the Suresnes weir head the Boulé shutters only will be considered, as the engineers of the Suresnes weir prefer the Boulé shutters to the Cameré curtains. The Boulé shutters are wooden panels $1.25^m \times 1.0^m$ which slide up and down the upstream faces of the frames and close the openings between the frames. The frames are ⊥ in shape on their upstream faces, and so the shutters are kept in position by the force of the water pressing them against the frames, the ⊥ shaped frames preventing them from moving horizontally. These panels are raised and lowered by means of a travelling crab with a ratchet bar. The Boulé shutters are exceedingly simple and work well.



The frames and shutters and general arrangement look complicated, but they work well and simply, there being a recess in one abutment and an ingenious arrangement for housing the end frames when they lie down.

The frames can be lowered in three hours and raised in five hours. As the pivots of necessity must have some play in the pivot blocks, the frames can never come into one straight line exactly and the leakage is not inconsiderable. I ought to add here that the leakage is principally owing to the large number of Cameré curtains employed. The Boulé shutters make a far more complete closure than the curtains can. In moving down the frames also, the shutters push all the rubbish sticking to the frames more or less out of the way ; while the curtains can do nothing to remove the rubbish, they simple unfold themselves over it and make a poor closure when there is much rubbish. No complete closure of a river could be attempted on this system and even on the Seine where they pass a minimum discharge of 45 cubic metres per second, they need considerable additions in the shape of cover pieces to keep up the water to the desired height. Besides this, the Seine is wonderfully clear of rubbish floating down, but on the Nile or Egyptian Canals where the amount of dura stalk and rubbish which floats down the current is always considerable, the frames would soon be completely buried under rubbish and regulation would be very difficult indeed.

If anything were to go wrong with the pivots or pivot blocks which are always buried under water, it might take considerable time to set it right.

But the whole system of regulation is an anachronism. In old days, they held up only a very moderate amount of water on the weirs, and then the navigable pass was often open and boats went up and down without any stoppage at the weir. Now however the head of water held up is very considerable, there is scarcely ever water enough in the river to dispense with the regulation and the boatmen on the Seine openly say that, if the lock walls and lock gates had been made sufficiently high to permit of their being used in flood, it would have been much better than the present arrangement. The navigable passes are of no use really. Large openings are needed, not for the passage of boats, but for the passage of ice when the Seine is frozen.

Each frame of the navigable pass cost L.E. 60 and the ties and additions L.E. 8 per frame. The frame work therefore cost L.E. 56 per running metre.

The moveable regulating apparatus consisting of shutters, travellers, etc., cost L.E. 74 per running metre or $\left(\frac{74}{4.6}\right)$ L.E. 16 per square metre of submerged area.

The total regulating apparatus of frames and shutters, etc., cost L.E. $\frac{56+74}{4.6}$ or L.E. 28.2 per square metre of submerged area.

The masonry of the floor cost L.E. 400 per running metre.

The total cost of the weir was therefore: —

Masonry floor........................	L.E. 400	per	running	metre.
Moveable frames.....................	» 56	»		»
Regalating apparatus.................	» 74	»		»
	L.E. 530	per	running	metre.

This sum does not include the charges of river training.

The following information might be useful: —

In the navigable pass, there were 7,365 cubic metres of masonry, including ashlar, this cost L.E. 28,669 or L.E. 3.9 per cubic metre for masonry in place in the foundation.

Pont aux Anglais Weir on the Seine, (S. of Paris).

Plate 9. This weir, like that at Suresnes, is provided with Poirée frames, but the regulating apparatus on the weir and the navigable pass is much more complicated. The system of regulation is known as the Chanoine system; a water tight closure with this system would be an absolute impossibility; while, in addition, a great part of the regulating apparatus as well as the Poirée frames are permanently below water level. The system has been practically condemned in France itself, as it is no longer a competitor by the side of the works of which Suresnes and Poses are examples. At the Pont aux Anglais weir, however, the escape has a depth of water on the floor of 2.30 metres and is closed by wooden needles 3.50 × .08 × .08 as given in detail on plate 9.

The bottoms of the verticals rest against a sill on the floor, whilst the upper ends rest against a horizontal bar fixed to the Poirée frames.

The needles are provided with iron hooks at their upper ends. These hooks are of the shape shown in the figure. They permit of the needles, not only being supported by the horizontal bar at their upper ends, but also of being able to revolve round it when the lower end is freed from the sill.

As a rule, an ordinary lever is applied to the projection B and the needle raised slightly above the sill, the force of the water immediately makes it fly round the bar A and rest on the water. It is removed by hand. In case of difficulty or emergency, the machine shown on plate 9 is run on to the site of the vertical and the vertical is raised by it. The guardian howewer told me that it was seldom necessary to use the machine, as he easily handled the needles under every condition of discharge.

The Poses Weir on the Seine near Rouen (France).

Plate 10. This weir was put into operation in September 1885.

The weir is situated on the main branch of the river at the downstream end of an island two kilometres in length, while there are three locks and a small weir situated on the

smaller branch of the river. The locks are $120^m \times 12^m \times 1^m.6$, $141^m \times 12^m \times 3^m.2$ & $42^m \times 8 \times 3^m.2$ (the third item is always the depth of water on the sill).

The weir is 244 metres in length made up of three deep openings of 28.2 metres width each, two escape openings of 28.2 metres width each, and two navigable openings of $32^m.5$ and $30^m.5$ metres width respectively. Between the openings are piers of 4 metres width each. The depth of water on the upstream side of sills of the deep and navigable openings is 5.0 metres and on the downstream side 1.0 metre, or a maximum head of water of 4 metres. The maximum flood level of the river is 6.3 metres above the floor of the navigable passes.

As at Suresnes, the navigable pass alone will be described.

Referring to the plan, it will be seen that the floor is 13 metres in width and 8.5 metres in depth resting on compact chalk, with an inconsiderable amount of pitching up and downstream. The floor is at about the bed level of the river.

The piers are 4 metres wide and 23 metres long at base and 21.5 metres long at top; they are 12.5 metres high at the roadway level and 16 metres high at the cutwaters. They are made massive as they have to stand the horizontal thrust of the water held up at the large openings.

The piers support two iron girder bridges. The lower bridge consists of two main lattice girders 3 metres deep and 3.50 metres apart supporting a roadway and carrying the iron bar on which the frames are hinged. The upper bridge is 7.50 metres wide and is raised 1.0 metre above the lower bridge. The upstream girder of the lower bridge is the downstream girder of the upper bridge, while the other girder has the same dimensions. The upper bridge carries two lines of rails on which run the travellers which lift frames out of the river. To this bridge also are attached hooks for catching and retaining the frames in a horizontal position, so as to leave a clear waterway for navigation when the weir is open.

Each frame, of which there are 13 in the smaller navigable pass and 14 in the larger, consists of 4 iron girders 11.5 metres in length, braced together so as to form a single frame occupying 2.32 metres in length of the horizontal bar to which they are hinged. At about high flood level, the frames support hinged cantilevers carrying a line of railway on which run the travelling crabs for winding and unwinding the curtains by which regulation is performed between the frames. When the frames have to be raised, the cantilevers lie flat against the frames, and frames, cantilevers and curtains rise together and are hooked on to the upper bridge. The free passage allowed for navigation between the frames, in their horizontal position, and the high water level is 4.50 metres. When regulation is necessary, the frames are lowered into position and rest against the sills. They are made truly vertical by driving small wooden wedges between the different frames along the cantilever roadway. The sills are made of iron and are imbedded in the masonry of the floor.

The curtains are 5.50 metres in length and 2.30 metres in width and consist of horizontal pieces of pine wood, $.078 \times .078$ in section ot the bottom and decreasing gradually to the top, hinged together at their upstream side. A chain passes round the curtain and enables it to be raised and lowerd by means of a crab. The leakage through the curtain is inconsiderable after it has been some time in the water, but it is almost impossible to get two curtains to exactly touch each other as they are unrolled against a head of water, and if any rubbish collects against the frames and cannot be removed, the curtains get displaced and allow considerable leakage. I know at Poses they have the very greatest difficulty to maintain the required head when the Seine is running its summer supply, and they have to use cover curtains and other expedients. In Egypt, where the canals are full of rubbish and dura, it would be absolutely impossible to keep the frames clear of rubbish so as to allow the curtains to roll over them. At Poses, there are 220 metres in length of opening with a 4 metre head and 45 cubic metres per second as the minimum discharge while, at the Barrage in Egypt, we have 610 metres in length of opening with a 4 metre head and do not pass $\frac{1}{4}$ of a cubic metre per second in summer.

The remarks made on the subject of the Navigable pass at Suresnes apply with greater force to Poses. Owing to the position of the locks on a separate channel and the small weir between them, it is impossible to use the locks in flood and the current through the navigable

pass of the main weir is so strong that if a tug is towing up four barges, it has to leave three and take up one at a time, which is greater waste of time than locking them at once. If the navigation canal was a short one, the little weir might be dispensed with and then the boats would be independent of the navigable pass.

The great advantage enjoyed by the Poses system over that at Suresnes is its greater power of being employed for great depths, and the position of the hinges of the frames which are alvays above water level instead of below it as at Suresnes.

The Masonry floor cost.....	L. E. 343	per running metre of opening.		
The piers cost.............	» 170	»	»	»
Total.....	513	»	»	»

The girder bridges cost....	L.E.	75	per running metre of opening.			
The frames..............	»	35	»	»	»	
The curtains.............	»	13	»	»	» (*)	
The machinery...........	»	5	»	»	»	
	L.E.	128	or L.E. 25.3 per square metre of water surface.			

As the masonry cost L.E. 513 per running metre, including the pier, the navigable pass cost L.E. 641 per running metre.

I consider Poses the best weir I saw in France. Though complicated it works easily and is wonderfully complete in its details.

Belleeck weir on the Lough Erne outlet (Ireland).

Plate 11. The weir consists of four openings of 8.90 metres width each, with piers 2.40 metres wide. The depth of water is 4.35 metres and the maximum head 4.35 metres. The weir is founded on very solid limestone rock. The piers are 13 8 metres long and 2.40 metres broad for a height of 5 metres above the sills; on these piers are erected masonry towers 2.4 metres wide and 2.7 metres long to support the light lattice bridges which carry the lifting gear and provide a footway and space for working the sluices by hand power.

The regulation is performed by Stoney's patent gates. The main principle of these sluice gates is the reduction of friction by putting a train of live rollers between the moving surfaces. Each roller frame is kept in position by a chain fastened at one end to the girder bridge over the opening, passing under a pulley fixed to the top of the frame, and then attached at the other end to the top of the gate. The gate in moving confers on the roller frame a velocity equal to half its own rate of motion. At Belleeck, the lifting of the gate is done by two 10 centimetre double threaded screws of 5 centimetres pitch; there is a screw at either end of the gate, working in a nut fixed in the gate itself. The gearing is so arranged that each gate may be lifted by one man, who takes 45 minutes to raise a gate 3 metres. The motion is as easy when the gates are holding up the full head of water as when they are in the air. Each gate weighs 13,000 kilograms, and there is no counterweight.

The maximum pressure on a gate is 86 tons, and as I had found by experiment at Ipswich that the pressure needed to start one of these gates was only about $\frac{1}{80}$ of the weight, I was not surprised that the water pressure was really insignificant compared to the weight of the gate.

The staunching at each vertical edge is done by a 5 centimetre turned bar, which hangs freely from the gate in a V groove, one side of which is formed by a planed casting fixed to the pier. and the other by a similar casting on the gate, coming within 1 centimetre of each other at the angle of the V.

Each opening cost L.E. 1000 exclusive of the masonry, so that the regulating apparatus cost $\left(\frac{1000}{8.9 \times 4.35}\right.$ or$\left.\right)$ L.E. 26 per square metre or L.E 112 per running metre.

The gates were completed in 1884 and have worked perfectly ever since. Each sluice can be made absolutely water tight when desired.

(*) Or L.E. 2.5 per square metre.

Lock regulator sluices and Weaver sluices on the Manchester Ship Canal (England).

The Weaver sluices consist of some 14 openings of 9.10 metres width each with piers of 2.80 metres width. The depth of water is 5.50 metres and that also is the maximum theoretical head. Plate 12.

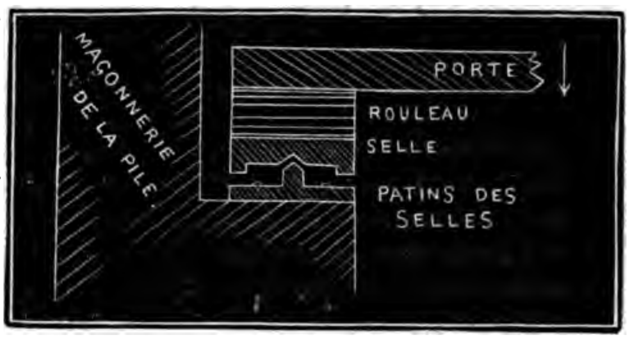
The works here are subjected to the action of a very heavy sea. The foundations are of no interest as good sandstone is met with almost immediately.

The piers are 11.50 metres long and 6.10 metres high, with towers 5.30 metres long and 5.10 metres high to carry the regulating apparatus and to allow of the housing of the gates when the regulator is open.

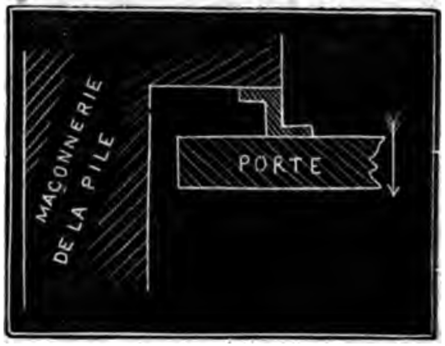
The regulation is performed by Stoney's patent roller gates. The sill are of iron but not brought to a sharp point as ordinarily, for the gates have been designed capable of holding up water on either side.

The towers support light girder-bridges, with the girders 1.20 metres deep and 3.20 metres apart, supporting roadways which carry the pulleys for the counterpoises and the winches for raising and lowering the gates.

The gates are constructed of steel and consist of the ordinary arrangement of girders with sheeting on one side. The gates are perfectly balanced by counterpoises by means of four wire ropes passing over two pulleys, one at either end of each gate. The winches for putting the gates in motion are at the middles of the bridges and are worked by hand.



The grooves have planed ⊥ shaped girders firmly fixed to their downstream faces as saddle bed plates. The saddles are of the same width as the length of the rollers and insure the rollers being always in touch along their whole length both with the gates and bearing surfaces of the saddles which transmit the pressures to the piers. The roller frames are supported in the same manner as they are supported at Belleeck.



The maximum pressure of water on one gate will be $(10 \times 5.5 \times \frac{5.5}{2}) = 150$ tons, and as the coefficient of friction is $\frac{1}{80}$, the force needed to move the gate against the pressure of the water will be 2 tons or 2000 kilograms.

The gates are made water tight by double L irons fixed to the upstream ends of the grooves and resting against the gates.

The lock Regulator or Byewash sluices. — These regulators have each three openings of 9.10 metres width each, with piers 3 metres wide. The foundations are on good sandstone.

The maximum depth of water and the maximum head possible is 7.90 metres.

The piers are 13.2 metres long and 9 metres high, with towers 5.5 metres long and 6 metres high for the regulating apparatus and allowing of the housing of the gates when the regulator is open.

The other details of this regulator are similar to those of the Weaver sluices except that the bridges are 3 metres wide and 10.5 metres above floor level.

The sills are of wrought iron and are brought to a sharp point projecting well above the floor to insure their being always clear of rubbish.

The maximum pressure which will ever come on any one of these gates will be $(10 \times 7.9 \times \frac{7.9}{2}) = 300$ tons approximately. The resistance to be overcome in raising the gates will be $(\frac{300}{80}) =$ about 4 tons or 4000 kilograms.

Gangara Regulator on the Rayah Tewfiki Canal (Egypt).

13 Plate. The Gangara regulator is the first ordinary regulator on the Rayah Tewfiki and consists of a regulator and lock combined. The lock is $50^m \times 8^m$.

The regulator has 6 openings of 3 metres width each with piers 1.40 metres wide.

The maximum depth of water is 6.30 metres and the maximum head 3.0 metres. It is built on good stiff clay.

The width of the floor is 16 metres and the depth 1.75 metres. The piers are 11 metres long and 6 metres high and support a roadway on their downstream side. On the upstream side they support towers .80 metres $\times$ 1.40 metres and 2.25 metres high, which carry a girder, while the upstream parapet of the bridge is raised to the same level as the girder. The upstream parapet and the towers carry a line of railway on which moves the travelling crab which works the gates. When not needed for regulation, the gates are housed between the towers and the upstream parapet.

The grooves are double and of cast iron.

The regulation of each opening is performed by two gates moving in the grooves. The lower gate is 1.00 metre high and the upper gate 3.00 metres high. The gates are made of wrought iron with the ordinary arrangement of girder and sheeting on one side. The lower gate is lowered and raised by means of suspension rods which rest in the grooves when the gate is down. The upper gate is raised and lowered by means of chains. The traveller is an ordinary winch on a carriage.

This regulator cost L.E. 16.867 and began working in 1889. The amount of iron work in each opening is —wrought iron 18,000 kilograms and cast iron 9,000 kilograms. The gates and over head platform of each opening cost L.E. 825.

The cost per running metre of floor is L.E. 42.

The cost of regulating apparatus per running metre of floor is L.E. 34.

The regulating apparatus cost L.E. 8.25 per square metre of sluice gate.

Rayah Tewfiki Canal Head Regulator (Egypt).

14 Plate. This regulator is at the head of the Rayah Tewfiki Canal where it takes off the main Nile. It was designed and built by Col. Western and Mr. Reid and opened in 1889.

The soil is a very light sand full of powerful springs; a worse soil could scarcely be found anywhere for a work of this kind.

The work consists of 6 openings of 5 metres width each, with piers two metres wide. On the left hand is a lock $50^m \times 8\frac{1}{2}^m$.

The maximum depth of water is 9 metres and the maximum head 4 metres in flood, so that this regulator is a good type of a heavily strained work on a bad foundation.

The floor proper is 24 metres in width and 2.5 metres in depth with an upstream masonry apron 22 metres wide and 1.50 metres deep and a downstream masonry apron 10 metres wide and 1.5 metres deep. There are 10 metres width of pitching upstream and 20 metres in width downstream of the aprons. The piers and abutments and lockwalls are founded on circular wells of 2.5 and 3.5 outside diametres respectively. These wells go down to a depth of 6 metres below the level of the top of the floor.

At a distance of 14 metres upstream of the floor proper and again at a distance of 7.5 metres downstream of the floor are rows of rectangular wells $3.5^m \times 2.5^m$ in outside measurement which descend to a depth of 6 metres below the level of the top of the floor. The wells are 0.30 metres apart and the spaces between are piled off and filled with quick setting concrete, so that these two rows of wells are like two solid curtains. The upstream curtain keeps off springs and the downstream curtain protects the work from scour. The wells were sunk by Bull's patent dredgers after the ordinary Indian method.

The piers are 15.5 metres in length at bottom and 9.5 metres high. They support a roadway 11 metres above floor level. Upstream of the Bridge, the piers support towers 1.60×2.60 and 2 metres high, which carry a girder. The top of the girder and the top of the upstream parapet of the Bridge are at one level. They carry a line of railway on which runs a powerful winch for lowering and raising the gates.

Below the main arches are blind arches 1.50 metres wide, so that each sluice is a clear opening 5 metres wide and 7.5 metres high.

The regulation of each opening is performed by two wrought iron gates moving in separate grooves and raised and lowered by the travelling winch. The two grooves are spaced .30 metres apart and have let in between them horizontal I girders and blocks of ashlar. The grooves are of cast iron.

In each groove there is a gate 3.50 metres high, provided with rollers whose axles are fixed to the gate. Each gate has three rollers on either side.

On the rise of the flood, as soon as the depth of water in the Canal is equal to the requirements, both the gates are lowered together until they both reach the floor and the whole discharge of the Canal passes over the tops of the gates. On the Nile still rising and necessitating the further closing of the opening, the downstream gate is raised by the winch and regulation is performed entirely by it; the upstream gate remains on the floor until the final complete opening of the regulator after the flood.

The reason why the two gates are lowered to the bottom together and then one of them is raised is that sufficient power can always be applied to a gate to raise it against a great pressure of water, but without screws or Stoney's rollers the gate could not descend against a head of water when the pressure of water×^{d} by the coefficient of friction exceeded the weight of the gate.

The regulator has been working since 1888 and has given perfect satisfaction even in the very high flood of 1892.

The regulator cost L. E. 60,000 including the lock.

The gates and overhead platform of each opening cost L. E. 550.

The cost per running metre of floor is approximately L. E. 350.

The cost of regulating apparatus per running metre of floor is L. E. 110.

The regulating apparatus cost L. E. 16 per square metre of sluice opening.

The Barrage on the Nile (Egypt).

These weirs were built across the heads of the Rosetta and Damietta branches of the Nile by Mougel Bey some 40 years ago. The Rosetta Barrage is 465 metres between the flanks and the Damietta Barrage is 535 metres. As originally built, the platforms of the weirs were flush with the river's bed. The width of the floor was 46 metres and the depth 3.75 metres. As repaired, the floor proper is 34 metres wide and 4.5 metres in thickness; the upstream apron is of masonry 25 metres wide and 1 metre deep, while the downstream apron is 15 metres wide and 2 metres deep near the floor and 1.5 metres at the end. Below the downstream apron are 30 metres in length of pitching. Plate 15.

It would have been better if the upstream apron had not started abruptly with a thickness of one metre from the main floor 4.5 metres thick. It might have been 3 metres thick near the floor and then gradually reduced to a thickness of one metre. As it is, a slight crack has appeared along the join. There should also have been a liberal provision of puddled clay upstream of the apron, overlaid with concrete.

The maximum depth of water on the floor in flood is 9 metres, but the Barrages are never regulated on at that time. Regulation begins when the depth of water on the floor is 4 metres, and 4 metres is the maximum head of water held up on the floor.

The piers are 15.5 metres long, 2 metres wide and 9.25 metres high. On their downstream sides, they support a roadway 8 metres wide. Upstream of the bridge, the piers support towers 1.5 metres long, 2 metres broad and 3.5 metres high which carry a girder. The top of the girder and the top of the upstream parapet of the bridge are at one level. They carry a line of railway on which runs a very powerful winch for raising and lowering the gates.

The regulation of each opening is performed by two wrought iron gates opening in a double cast iron grooves and raised and lowered by the travelling winch. The lower gate is 2.0 metres high and the upper 2.5 metres high. They are provided with rollers. Each gate has 4 rollers, two on either side.

The new system of regulation has been in operation since 1889 and has answered very well. When the gates are all closed, the discharge of the Nile through the Barrage is nil.

No exact information exists of the cost of the original work, but the work of repairing cost L. E. 465,000.

The gates and overhead platform of each opening cost L. E. 500.

The cost of repairing per running metre of floor was L. E. 528.

The cost of the regulating apparatus per running metre was L. E. 100.

The regulating apparatus cost L.E. 22.5 per square metre of sluice gate.

Koshesha Escape Regulator (Egypt).

Plate 10. The regulator, designed by Colonel Western and Mr Reid and constructed by Mr Hewat, is built on the tail escape of the series of basins from Assiout to Wasta. It consists of 60 openings, each 3 metres wide. The piers are 1.30 metres wide.

The regulator is founded on good clay soil. The maximum depth of water on the floor was expected to be 6.50 metres, though it rose to 7.00 metres in 1892. The maximum head of water is 4.00 metres.

The main floor is of masonry 13 metres wide and 2.75 metres deep; the bottom of the foundation is below the minimum summer water level of the Nile. The upstream apron is of masonry 10 metres wide and 1.0 metre deep. The downstream apron is of masonry 12 metres wide and 2 metres deep. Below the downstream apron is 10 metres width of masonry blocks 1 metre deep, and below that again 20 metres in width of rubble pitching.

The piers are 12.5 metres long and 6.5 metres high and support a roadway on their downstream side. On the upstream side, they support two towers each .80 metres long, 1.30 metres wide and 1.0 metre high.

The depth of each opening is divided into two sluices by an arch thrown between the piers.

The lower sluice is 2 metres high and the upper 3.5 metres high.

The lower sluice is closed by a vertical gate moving in vertical grooves in the piers.

The upper sluice is closed by a drop gate hinged at its bottom to its floor and falling flat on the floor when open. Both gates are of wrought iron.

The two rows of towers carry girders and a line of railway on which travels the winch which raises and lowers the lower sluice gates in flood when the regulator is being worked. The winch is also employed to raise the upper drop gate into its vertical position after the flood is over and the regulator is in the dry (*).

The upper drop gates are kept in a vertical position (1) by hooks suspended from bolts fixed in the piers and dropping into eye bolts in the gates near the piers, and (2) by chains attached to the same bolts in the piers and clipped by a clip at the middle of the gate.

(*) There are in reality two winches in order to expedite the opening of the sluices.

When the gate is up and under water pressure, the hooks take the strain ; when the time for opening has come, the hooks are detached and the clip links are struck off and the gates fall instantly.

The regulator has worked through the flood of 1891 and 1892 and has given satisfaction. It cost L. E. 62,620.

The amount of iron work in sixty openings was : —

Cast iron....................	205,800	kilograms
Wrought iron...............	367,500	»
	573,300	

The gates and overhead platform of each opening cost L. E. 223.5.

The cost of floor per running metre was L. E. 90.

The cost of regulating apparatus per running metre was L. E. 74.5.

The regulating apparatus cost L. E. 14 per square metre of sluice gates.

The Rayah Menoufieh Head (Egypt).

This work is at the head of the Rayah Menoufieh Canal, at the very apex of the Delta. It was completed in 1867 and has been working ever since. In 1887, it was thoroughly repaired. Plate 17.

The regulator consists of seven openings of 4.16 metres width each and a lock $50^m \times 8^m$. The piers are two metres wide.

The maximum depth of water upstream is 9 metres, and the maximum head 3.70 metres.

It was built on the same principle as the Barrages. The floor is some 34 metres wide and 4 metres deep, and provided with pitching on its downstream side. It is founded on sand.

The piers are 14 metres long and 8.5 metres high and support pointed arches carrying a roadway 11.4 metres above floor level. The cutwaters are 9.30 metres high.

The system of regulation is that in ordinary use in Lower Egypt, viz: wooden needles or verticals resting against iron girders. The girders are bolted to vertical wooden frames which move in the grooves. The vertical timbers are all 25×15 centimetres in section. The verticals are lowered in front of the girders and rest against them. The great advantage of this system is the ability of being able to work in the deepest water and against any head with great safety. A water tight joint is however impossible in great depths of water. To lower the needles, a pair of shear legs is erected over each opening, and the needles are lifted off the roadway by a $3 \frac{1''}{2}$ rope working over a pulley supported by the shear legs and they are lowered in front of the horizontal girders. The force of the water drives the needles against the frames. When a sufficient number of verticals has been lowered, they are spaced and driven down to the floor by a monkey attached to the rope passing over the pulley. For lifting the verticals, if the head of water is over 1 metre, a chain is attached to the head of vertical, the other end of the chain is attached to a loose needle lying on the bridge and making use of the parapet of the bridge as a fulcrum the vertical is raised. The final operation of lifting the vertical out of the water and lying it on the roadway is performed by the rope passing over the pulley.

There are many modifications. In the most recent cases, the iron girders have been replaced by lighter girders of steel and wooden frames at the ends by hollow cast iron cylinders supporting the girders at their ends, while a long iron rod ties the girders and cylinders together, and permits of the ready lowering and raising of the whole number of girders when the floods have passed.

The girders, verticals, frames, shear legs, &c., cost about L. E. 80 per opening, i. e. L. E. 25 per running metre or L. E. 2.8 per square metre of opening.

Abu Shusha Escape Regulator (Egypt).

17 Continued. This is a type drawing of one of the new regulators designed by Col. Ross and built on firm clay soil on the Basin Canals and escapes of Upper Egypt.

The regulator has 7 openings of 3 metres each and is capable of holding up water on either side.

The maximum depth of water is 4.5 metres and the maximum head 3.0 metres.

The floor is 19 metres long and 1 metre deep with an upstream and downstream curtain each 1.5 metres broad and 3 metres deep. The downstream apron is 10 metres long, on a slope, 0.50 metres deep, with a curtain wall 1.5×1.5 metres at the end.

The piers are 11 metres long and 5.40 metres high and support arches carrying a roadway. The cutwaters are provided with cast iron grooves and carry a line of railway on which moves the traveller for raising and lowering the sleepers.

The regulation is performed by horizontal sleepers of timber. All details are freely given on plate 17.

The conditions prevailing in the basins of Upper Egypt do not necessitate the lowering of these horizontal sleepers against great heads of water, and so the system works well.

Regulation on this principle would cost L. E. 2.0 per square metre of closed opening for grooves, rails, travellers, slipers, &c

Dowlaishwerân Regulator (Madras, India).

Plate 18. The regulator was built in 1846-1848 and has been working since.

There are 3 main openings, each 12.19 metres wide, with piers 2.19 metres wide. Each main opening is subdivided into 5 openings of 1.83 metres width by piers .76 metres wide. There is a small lock on the left flank.

The maximum depth of water on the upstream side is 6.20 metres and the maximum head is 3.80 metres.

This work is constructed entirely on sand.

The main floor consists of a mass of masonry 10 metres wide and 1.8 metres deep, with a downstream apron of masonry 5 metres wide and 1 metre deep. The downstream curtain is a row of wells 1.:0 metres in external diametre which descend to a depth of 3 metres below floor level.

This floor seems exceedingly light for such an important work built entirely on sand.

There are 10 metres of pitching upstream of the floor and 40 metres of pitching downstream of the floor with a thickness of from .80 to 1.30 metres.

The main piers are 10.3 metres long, 2.19 metres wide and 3.5 metres high; they support arches of 12.19 metres span.

The cutwaters are 6.70 metres high.

The smaller piers are .76 metres wide, 3.4 metres long and 3.05 metres high, supporting arches and a blind wall 1 metre wide between the lower arches and the main arch.

At a height of 2.44 metres above the floor, the small openings are spanned by ashlar lintels .25 metres wide, which support a blind wall between the lintels and the lower arches.

The area of each sluice opening is therefore 1.83×2.44 metres.

The cutwaters of the smaller piers are also 6.70 metres high.

The cutwaters are provided with double grooves, in which move two wooden gates each 1.30 metres in height which regulate the openings by means of screws. The capstans for working the screw lifting gear are at the level of the tops of the cutwaters.

Bobberlanka Regulator (Madras, India).

Built in 1879 at a cost of L.E. 8,081. Plate 19.

There are 5 main openings of 7.32 metres width each, with piers 1.22 metres wide.

Each main opening is subdivided into 3 openings of 1.83 metres width each by piers .92 metres wide.

The maximum depth of water on the upstream side is 6.20 metres, and the maximum head 3.80 metres.

The regulator is built entirely on sand.

The main floor consists of a mass of masonry 14 metres wide and 1.80 metres thick with a downstream apron 8 metres wide and 1 metre thick. The downstream curtain is a row of wells 1.80 metres external width and 6.0 metres below the level of the floor. The upstream curtain is a double row of wells 1.80 metres external width and 6 metres below the level of the floor. The space between the two row of wells of the upstream curtain is filled with concrete. The total width of the upstream curtain is 5.3 metres.

The pitching downstream is 15 metres wide and 1 metre deep. The upstream pitching is 6 metres wide and 1 metre deep.

The main piers are 8.25 metres long, 1.22 metres broad, and 3.05 metres high and support an arch 7.32 metres span. The cutwaters are 7 metres high.

The smaller piers are 4.0 metres long, .92 metres wide and 2.6 metres high supporting arches and a blind wall 1 metre wide between the upper and lower arches.

The sluice openings are 1.83^{m}×3.05 metres.

The cutwaters of the smaller piers are 7.00 metres high.

The cutwaters are provided with treble grooves in which move 3 gates; each gate is 1.05 metres high and made of wood. The gates regulate the sluices by means of screw lift gear. The capstans for working the gear are at the level of the tops of the cntwaters.

Tinnevelly Channel Regulator (Madras, India).

This work was constructed in 1878 for L. E. 1656. It consists of 3 main openings of 3.10 metres width, with piers .80 metres wide. Plate 20.

Each main opening is subdivided into 2 openings of 1.25 metres each with a pier .60 metres wide between. The work is built on ordinary clay soil.

The maximum depth of water on the upstream side is 5.30 metres and the maximum head 3.80 metres.

The floor consists of a mass of masonry 14.70 metres wide and 1.20 metres deep, with upstream, middle and downstream curtain walls, each 1.50 metres wide and descending to a depth of 1.80 metres below floor level.

The upstream pitching is 3.50 metres wide and .75 metres deep, while the downstream pitching is 17.5 metres wide and .75 metres deep.

The main piers are 7.30 metres long, .80 metres broad and 4.10 metres span. The cutwaters are 6.30 metres high.

The small piers are 1.50 metres long, .60 metres broad and 1.40 metres high supporting arches and a blind wall between the lower and upper arches.

The openings are 1.25 metres wide and 1.80 metres high. There are 6 of them.

The cutwaters of the smaller piers are all 3.30 metres high and support arches and a platform 4.40 metres above floor level. The cutwaters are provided with single grooves in which move gates for regulating the openings by means of screw lifting gear worked by capstans at the platform level.

The screw boxes are liable to be drowned in very heavy flood.

Khannadien Channel Regulator (India).

Plate 21. This is similar in principle to the last; with only a slight difference in detail.

The work was built in 1878 for L. E. 665.

The details of shutters and screw boxes are given as good examples of this kind of work.

The regulator consists of four sluices 1.40 metres broad × 2.10 metres high. The upstream depth of water is 5.50 and the maximum head is 3.60 metres.

Bêtwa Canal Head and Undersluices (India).

Plate 22. The Bêtwa weir, built across the Bêtwa river in Upper India on a granite bar at the head of the Paricha rapids, is provided with a set of undersluices, and adjoining the undersluices is the Canal Head. The cross section of the weir and full details of the undersluices and Canal Head are given on plate 22.

The whole work is founded on solid granite. The undersluices and Canal head were begun in 1881 and completed in 1885 at a cost of L. E. 25,000.

The maximum depth of water on the upstream side is 12.20 metres and the maximum head 10 metres.

The Canal Head consists of five openings of 1.83 metres width each, with piers 1.22 metres wide. The roadway is 13.3 metres above the floor and the cutwaters are 11.60 metres above the floor. The floor is 17.50 metres long. Each opening has two sluices of 1.83 × 1.83 metres, while the balance of the space is closed by a dead wall. One set of sluices is at the floor level and the other set 5 metres above the floor level. When the reservoir is full and when the river is in flood, the upper sluices are used, and when the level of the reservoir has fallen, the lower sluices are used. The sluice gates are of iron and are raised and lowered by screw lifting apparatus with the screw boxes at the level of the tops of the cutwaters 11.60 metres above floor level. Upstream of the sluice are safety grooves. Upstream of the roadway and downstream of the cistern into which the sluices discharge, is another set of safety grooves with drop gates, while downstream of the roadway is a third set of safety grooves. So far, the sluice gates alone have been used. Maximum depth of water 11.6. Maximum head 10.0 metres.

The Undersluices consist of four openings of 1.83 metres width each, with piers 1.22 metres wide. The width of floor is 14 metres. The roadway is 12.20 metres above floor. Each opening has one sluice of 1.83×3.66 metres at floor level, while the rest is closed by a dead wall. The sluice gates are of iron and are provided with screw lifting apparatus with the screw boxes at the roadway level. There is one safety groove upstream of the sluices and another downstream of the roadway. The water approaching the sluice is trained through gradually decreasing openings, so as to increase the coefficient of velocity.

The undersluices and Canal head are built of first class sandstone ashlar.

The total regulating apparatus, grooves, gates, safety valves, &c., cost L. E. 5,500 for 95 square metres of sluice opening, but as there are so many safety grooves, it is difficult to give the exact figure of the sluices. They may be put down at L. E. 30 per square metre.

The maximum depth of water is 12.2 metres and the maximum head 8.4 metres.

Narora Weir Undersluices (India).

The Narora weir is a solid dam thrown across the Ganges river, with its crest 3 metres above the normal bed level of the river. Plate 23.

The undersluices are situated near the Canal head in order to keep the deep channel of the river near the Canal head. The floor is on the same level as the Canal bed. The undersluices consist of openings of 2.13 metres width each, with piers .76 metres wide between.

The maximum depth of water is 4 metres and the maximum head 2.5 metres.

The works are founded on sand.

The main floor is 15.3 metres wide and 1.80 metres deep with an upstream curtain of wells 5 metres below floor level and 1.83 metres broad. There is also a downstream curtain of wells 3.5 metres below floor level and 1.83 metres broad. Downstream of the floor, is an apron of pitching 30 metres long and .50 metres deep. The upstream apron is 9.5 metres long and 1.3 metres deep.

The undersluice regulating gates are over the upstream wells.

The piers are 8.70 metres long and 4.5 metres high. They support a roadway 5.70 metres above the floor. Upstream of the roadway the cutwaters are raised to the same level as the roadway.

The sluices are 2.13 metres wide and 3.3 metres high and are regulated by wooden gates 2.4×3.3 metres moving in vertical grooves, and raised and lowered by means of a winch travelling on rails about 7 metres above the floor level.

The floor cost about L. E. 120 per running metre. The work was completed in 1874 and has been working since.

W. Willcocks.

Cairo, January 1893.

APPENDIX III.

THE NILE.

THE NILE.

1. — The Nile drains nearly the whole of North Eastern Africa, an area comprising 3,110,000 square kilometres. Its main tributary, the White Nile, has its sources to the south of Lake Victoria and has traversed over 3,500 kilometres before it is joined by the Blue Nile at Khartoum. From the junction onwards the river is known as the Nile, and after a further course of 3,000 kilometres flows into the Mediterranean Sea by the Rosetta and Damietta mouths. The modulus of the Nile at Assuân is 2,990 cubic metres per second and at Cairo 2,610 cubic metres per second. **The White Nile from Lake Victoria to Gondokoro.**

2. — Lake Victoria, covering an area of 70,000 square kilometres is the first reservoir of the Nile. The Equator passes through this lake which lies in the region of almost perpetual rains and receives an excessive supply of water from its western tributaries, from subsoil springs, and heavy rainfall. Owing to its great extent, the fluctuations of water level are very slight. Stanley considered the discharge of the White Nile as it left Lake Victoria as $\frac{1}{3}$ greater than that of the Tangouri, the principal affluent of the lake. Judging from recorded observations further down the river (1), the mean discharge of the lake is probably 1000 cubic metres per second (2). Shortly after leaving Lake Victoria, The White Nile descends the Ripon Falls on a width of 400 metres and a drop of 4 metres. Lake Victoria lies about 1130 metres above sea level and is 500 metres higher than Lake Albert. Between these lakes, on a distance of 480 kilometres the White Nile (known here as the Somerset) traverses at first the succession of the swamps known as the Ibrahimia Lake, and then taking the character of a mountain torrent precipitates itself into the north eastern corner of Lake Albert. The survey of Lake Albert, which has an area of 4,500 square kilometres, was made in 1877 by Mason Bey (3), and he recorded the fact that the lake was 1.20 metres below its high water level. The rainfall of that year was deficient in the whole of the Nile Valley, and the summer supply of the Nile in Egypt was the lowest of which there is any record. In July 1892 Captain Lugard noticed that Lake Victoria was considerably above its normal level after the heavy rains of that year, and the summer supply of the Nile in 1893 has only twice been exceeded according to our records. Lake Edward with a probably area of 4,000 square kilometres and a height above sea level of 880 metres is a feeder of Lake Albert. After leaving Lake Albert the White Nile floows for 200 kilometres in a deep broad arm with scarcely any slope and scarcely any velocity as far as Dufflé, and then after a short troubled course tosses over the Fola falls on a width of 90 metres, and continues as a torrent for another 200 kilometres to a short distance south of Gondokoro. At Gondokoro the river is 2 metres deep at low water, and only 4.50 metres deep in flood, the discharge ranging between 500 and 1,600 cubic metres per second (1) and (2). The regulating effect of the great lakes is well felt here. It is one of the keys for understanding the flow of the Nile and will be dwelt on later in this paper. At Gondokoro the river is at its lowest in winter, it begins to rise about the 15th April and reaches its maximum between 15th and 30th August (2) (4).

(1) « *Le Nil, le Soudan, l'Egypte* » by A. Chelu, page 12, Paris 1891. The figures should be 500 and 1.600 instead of 550 and 1,200. It is unfortunate that in his other discharges Mr. Chelu has not separated his observed discharges from his interpolations.

(2) « *Saggio idrolico sul Nilo* » by E. Lombardini, page 35, Milano 1864. Lombardini estimated 800 cubic metres per second. See also plate 3 figure (4) of his book for an interesting flood diagram at Gondokoro.

(3) Khedivial Geographical Society's journal, Cairo 1877.

(4) I take this opportunity of recording my obligations to Sir Samuel Baker for much information about the White Nile and its tributaries.

The White Nile from Gondokoro to Khartoum.

3. — From Gondokoro to Bôr, a distance of about 120 kilometres, the river keeps in one channel and has a rapid fall, while from Bôr to the mouth of the Gazelle River, on a further reach of 380 kilometres, the river divides into numerous channels and has a very feeble slope. The main channel is known as the Bahr el Gebel (the mountain stream) and is the one always used for navigation. In this reach are the "sadds" or dams of living vegetation which at times are capable of barring the surface and completely blocking navigation. The Gazelle River joins the White Nile on its left bank and has a feeble discharge in summer, though occasionally it exceeds the Bahr el Gebel in flood.

4. — At the junction of the Gazelle River and White Nile is a lake of an area of some 150 square kilometres in summer. During this latter period, in years of scanty rainfall, all this part of the river acts as an evaporating basin and a source of loss to the Nile. The waters of the river likewise become polluted here with decaying vegetable matter, which at certain time of the year imparts a green colour to the Nile as far north as Cairo. A hundred kilometres below the Gazelle River the White Nile is joined by the Saubat river on its right bank. During flood this river has a discharge nearly equal to that of the White Nile above the junction, while in summer it has a feeble discharge and is occasionally quite dry. From the junction of the Saubat to Khartoum, on a length of 900 kilometres the White Nile has a mean width of 1,700 metres, a depth varying from 5 metres in low supply to 7.5 metres in flood, and is a sluggish stream. The action of the current is always on the right bank owing to the prevailing north-west winds, and this action is continued during the whole of the remaining course of the river as far as the sea. The soil from the Saubat river to Khartoum is light and friable, and the White Nile in spite of its moderate velocity has a width 160 times its depth in flood.

The Nile at Khartoum.

5. — At a point 3,009 kilometres from the sea and 390 metres above it, is the town of Khartoum where the Blue Nile from Abyssinia joints the White Nile. The Blue Nile has its sources in the Mountains of Abyssinia where Lake Tsana — with an area of 3,000 square kilometres and height above sea level of 1,780 metres — is another reservoir of the Nile. The Blue Nile has a length of 1,350 kilometres. This river is comparatively clear in summer, but during flood, i. e. from the beginning of June to the end of October, it is of a reddish brown colour, highly charged with alluvium. The Khartoum Nile gauge, which was read from 1869 to 1883 used to stand on the Blue Nile about 5 kilometres above its junction with the White Nile, and its recorded readings are not exact records of the Nile. In flood the discharges of the two rivers are nearly equal, but in summer the White Nile is the main source of supply. The Nile here has a mean range of 6.50 metres between high and low supply with a maximum of 7.80 metres and a minimum of 5.30 metres. From comparisons with the Assuân gauge and observed discharges referred to the Khartoum gauge it is probable that the high supply varies between 11,100 and 5,200 cubic metres per second, with a mean discharge of 8,000 cubic metres per second, while the low supply varies between 1,500 and 320 cubic metres per second, with a mean discharge of 550 cubic metres per second(1). April is the lowest month and September the highest.

The Nile from Khartoum to Assuân.

6. — At at distance of 86 kilometres downstream of Khartoum is the 6th Cataract. Here the Nile descends 6 metres on a length of 18,000 metres. At a distance of 320 kilometres from Khartoum the Nile is joined by the Atbara river. This latter is another stream fed by the Abyssinian torrents, and though dry in summer, is a considerable river in flood. Heavily charged with volcanic detritus, it provides the greater part of the rich fertilising mud which the Nile carries in flood. The Atbara has a range of 8 metres, and from calculations and

(1) « *Géographie Universelle* » by E. Reclus, vol. X, page 77, Paris 1884. Linant Pasha made the high flood discharges of the White and Blue Niles 5,000 and 6,100 cubic metres per second, and the low summer discharges 300 and 160 respectively.

comparisons, I estimate that its floods range between 4,900 and 1,600 cubic metres per second, with a mean high flood of 3,100 cubic metres for second. It is in flood from July to October, with its ordinary maximum in August. Below the Atbara junction the Nile has no tributary, and flows throughout its 2,700 kilometres to the sea, a solitary stream. Traversing one of the greatest deserts on the globe, it is the sole source of life and vigour to whatever exists on its banks.

7. — Twenty-four kilometres downstream of the Atbara junction is Berber, and 45 kilometres downstream of Berber is the beginning of 5th Cataract, which has a length of 160 kilometres and a drop of 63 metres with three principal rapids, the Solimania Baggàra and Mograt. The village of Abu Hamed is situated at the foot of this Cataract. Between Abu Hamed and Dongola is the 4th Cataract, which begins at a point of 97 kilometres downstream of Abu Hamed, and has a length of 110 kilometres with a drop of 49 metres. In this series of rapids are the Um Dàras and Guerendid. Between the 4th and 3rd Cataracts is a reach of 313 kilometres on a slope $\frac{1}{12,000}$. On this reach is the town of Dongola. The 3rd Cataract has a length of 72 kilometres and a drop of 11 metres with the Hannek and Kaibàr rapids, surveyed and levelled by De Gottberg in 1857 [1]. Upstream of the Hannek rapid on the left bank of the Nile is the termination of the long depression in the deserts which goes by the name of the Wady el Kab and is considered by many as lower than the Nile valley [2]. Between the 3rd and 2nd Cataract is an ordinary reach of 118 kilometres. West of this part of the Nile are the Selima Wells [3] and according to some travellers an old abandoned course of the Nile slightly above the present high level of the river. This waterless river terminates in the Oasis of Berys which is separated from the Khargeh Oasis by a limestone ridge.

8. — The second Cataract, known as the "Batn el Haggar", has a length of 200 kilometres and a drop of 66 metres with the rapids of Amàra, Dal, Semna and Abka. At Semna are the rocks where Lepsius discovered the Nile gauges cut by one of the Pharaohs some 4,000 years ago [4]. The Nile flood recorded there is 8 metres higher than any flood of day. As the Nile at Semna could be very easily barred by a dam, it struck me when I was there in 1892 that probably king Amenemhat (of lake Mœris fame) had tried to bar the river with a dam in the hope of creating a reservoir. At Wady Halfa, near the foot of the second Cataract, a masonry gauge divided into metres, has been erected and read since 1877. Its accidental zero is R. L. 116.69 and the mean low water level or true zero is R. L. 117.89 [5]. Between the 1st and 2nd Cataracts, the Nile has a length of 345 kilometres and a slope of $\frac{1}{12,500}$. The mean width of the river is 500 metres, and the mean depths in flood and summer are 9 and 2 metres. The velocity in summer falls to 50 centimetres per second and rises to 2 metres per second in flood. The river in this reach is generally within sandstone, and the greater part is provided with gigantic spurs on both banks. These spurs perform the double work of collecting soil on the sides in flood and training the river in summer. They were probably put up by the great Ramses 3,000 years ago, as some of the most massive of them have evidently been constructed to turn the river on a curve out its natural channel on to the opposite side in order to secure deep water in front of his temple of Jerf Husain ("Jerf" means steep, scoured bank). The spurs have been constructed with care, and as the course of roughly dressed stone can be examined at fairly low water (I have never seen them at absolutely low water) it is evident that there has been no great degradation of the

(1) See the plan and section of the Kaibar cataract on plate I of this report.
(2) « *Géographie Universelle* », vol. X, page 457. See the enlarged plan of this part of the Nile on plate I of this report.
(3) The rocks at Selima are limestone.
(4) Mr. Coteril made a section of the river here for Count de la Motte.
(5) I have adopted everywhere the mean low water level as the natural zero of the gauge. Everything above is +, and below —. All the tables accompanying this appendix are referred to the mean low water level as zero.

bed during the last 2,000 or 3,000 years. The first, or Assuân Cataract, has a drop of 5 metres on a length of 5 kilometres.

9. — From Khartoum to Assuân, on a total length of 1809 kilometres, there are 565 kilometres of so called Cataracts with a total drop of 200 metres, and 1,244 kilometres of ordinary channel with a total drop of 95 metres.

The Nile at Assuân.

10. — At the foot of the 1st Cataract, opposite the town of Assuân, on the Island of Elephantine, has stood a Nile gauge from very ancient times. An officer belonging to the Roman Garrison in the time of the Emperor Severus marked an extraordinary high flood on the gauge. The maximum flood-mark at the time of the visit of Napoleon's French savants was however 2.11 metres higher than the above. As the middle of Severus' reign was A. D. 200, and the visit of French savants A. D. 1800, they concluded that the bed and banks of the Nile had risen 2.11 metres in 1600 years or 0.132 metres per 100 years. The new gauge divided into cubits and twenty-fourths was erected in 1869 and has been recorded daily since then (a cubit = 54 centimetres). Its accidental zero is R. L. 84.16. The mean low water level or true zero is R. L. 85.00.

The Nile from Assuân to Cairo.

11. — From Assuân to the Barrage, the length of the river is 973 kilometres in summer and 923 in flood. The slope in summer is $\frac{1}{13000}$ and in flood $\frac{1}{12200}$. The mean fall of the valley is $\frac{1}{10800}$. Referring to table IX, it will be seen that the slopes vary in the different mean reaches, the least being $\frac{1}{14800}$ in the Kena Mudiria and the greatest $\frac{1}{11400}$ in Beni Suêf. Turning to table X, it will be seen that in a high flood with a rise of 9 metres at Assuan, the rise in Kena will be 9.5 metres and only 8.2 in Beni Suêf. Table XI gives the mean areas of cross sections of the Nile, while table XIII gives the mean widths. Neglecting spill channels, we may state that in a high flood the mean area of the section of the Nile is 7500 square metres and the mean width 900 metres. In the Kena Mudiria, the area is 7000 square metres and the width 800 metres, while in Beni Suêf the mean area is 8000 square metres and the mean width 1000 metres. Speaking generally it may be stated that where the Nile valley is narrow the slope of the river is small, its depth great and width contracted; while where the valley is broad the slope is great, the depth small and the width enlarged. The mean velocity in flood ranges between 2.0 metres and 1.0 metre per second, while the velocity in summer varies from metre .3 to .7 metre per second. We may say that the Nile in soil has a natural section whose width in flood is 110 times its depth, while its mean velocity is 1.50 metres per second.

The natural canals, which take off the river and which never silt, have a mean velocity of some 70 centimetres per second, while the proportion of width to depth is about 12 to 1. Artificial canals of this section do not silt if their velocities are 80 centimetres per second, while silting takes place as readily when the velocity is greater as when it is less than the above. In muddy streams, like the Nile in flood, certain velocities demand certain proportions of width to depth, and if these are not given to it, they will make it for themselves by eating away the sides if they can, or by silting up and raising the bed, if they cannot eat away the sides.

The Nile at Cairo.

12. — On Roda island, opposite Cairo, has stood a gauge from the earliest times. It has been frequently reconstructed. The present gauge is reputed to have been erected in A. D. 861 with its zero at the same level as a more ancient one whose readings have been preserved since A. D. 641. When the gauge was constructed, a reading of 16 cubits meant the lowest level at which flood irrigation could be insured everywhere. The level to-day is 20 $\frac{1}{2}$ cubits on the gauge and the difference between them is 1.22 metres. As 1026 years have elapsed since the construction of the gauge it means a rise of 12 centimetres per 100 years. This is slightly under the rise calculated at Assuân.

The following table gives the means of the maximum flood and low water levels per century: —

7th century	17.5	R.L. flood	11.5	R.L. low water	6.0	Difference.
8th »	17.4	»	10.8	» »	6.6	»
9th »	17.5	»	11.5	» »	6.0	»
10th »	17.5	»	11.3	» »	6.2	»
11th »	17.5	»	11.6	» »	5.9	»
12th »	17.7	»	12.2	» »	5.5	»
13th »	17.7	»	11.4	» »	6.3	»
14th »	17.9	»	11.1	» »	6.8	»
15th »	18.2	»	11.8	» »	6.4	»
16th »	18.4	»	11.9	» »	6.5	»
17th »	18.8	»	11.8	» »	7.0	»
18th »	19.1	»	11.8	» »	7.3	»
19th »	19.5	»	12.3	» »	7.2	»

It is evident from the above that the head of the Delta, or the bifurcation of the Nile, was much nearer to Cairo in early days than just now, and the last three centuries have seen great changes. The fall of watersurface is very considerable at every bifurcation, and the difference between mean high and low supply at the Barrage to-day is 6.0 metres against 7.2 metres at Cairo. Judging from the above figures, I should say that from the 7th to the 12th century the bifurcation was gradually approaching Cairo, while since the 12th it has been receding.

13. — At Assuan the Nile has a mean range of 7.90 metres between high and low supply, with a maximum of 9.80 metres and a minimum of 6.40 metres. The high supply varies between 13,200 and 6,500 cubic metres per second, with a mean of 10,000 cubic metres per second, while the low supply varies between 210 and 1,300 cubic metres per second with a mean of 410 cubic metres per second. September is generally the highest month and May the lowest. The mean low water level is R.L. 85.00. **Assuân.**

14. — At Cairo the Nile has a mean range of 7.00 metres with a maximum of 9.6 metres and a minimum of 5.3 metres. The high supply varies between 12,000 and 4,800 cubic metres per second with a mean of 7,600 cubic metres per second, while the low supply varies between 1,300 and 170 cubic metres per second, with a mean of 380 cubic metres per second. October is the highest month and June the lowest. The mean low water level is at R.L. 12.25. **Cairo.**

15. — The approximate areas of the catchment basins of the Nile and its tributaries are as follows: — **The Catchment basin of the Nile.**

	Square kilometres.
1. The White Nile at the Ripon falls	260,000
2. The White Nile between the Ripon and Fola Falls	130,000
3. The White Nile between the Fola Falls and Gondokoro	60,000
4. The White Nile between Gondokoro and the Saubat Junction	190,000
5. The Gazelle River	220,000
6. The Arab River	340,000
7. The Saubat River	130,000
8. The White Nile between the Saubat junction and Khartoum	320,000
9. The Blue Nile	310,000
10. The Atbara and Gaash	240,000
11. The Desert north of Khartoum	910,000
The Nile	3,110,000

The rainfall in the Nile valley

16. — The rainfall about Lakes Victoria and Albert and about Gondokoro and the upper halves of the Saubat, Blue Nile and Athbara may be taken as 2 metres per annum. In the Eastern half of the Gazelle river, the lover half of the Saubat, and middle third of the Atbara, 1 metre per annum may be taken as the rainfall. The western half of the Gazelle River has probably 50 centimetres per annum, while the Arab River and tail portions of the White and Blue Niles and the Atbara cannot have more than 25 centimetres per annum. From Berber northwards there is a very scanty rainfall indeed, and the country is considered rainless. Applying these rainfalls to the catchment basins we obtain the total mean annual rainfall in the Nile valley as follows: —

	Square kilometres		Metres		Cubic metres
1.	260,000	×	1.5	=	390.000,000,000
2.	130,000	×	2·0	=	260.000,000,000
3.	60,000	×	2.0	=	120,000,000,000
4.	190,000	×	1.5	=	285.000,000,000
5.	220,000	×	0.75	=	165,000,000,000
6.	340,000	×	0.25	=	85,000,000,000
7.	130,000	×	2.00	=	260,000,000,000
8.	320,000	×	0.30	=	96,000,000,000
9.	310,000	×	1.70	=	527.000.000,000
10.	240,000	×	1.40	=	336,000,000,000
11.	910,000	×	0.12	=	109,000,000,000
	3,110,000	×	0.84	=	2.633,000,000,000

17. — If we examine the plan and note the lengths of the different rivers and their slopes, it will be evident that the Saubat, the Blue Nile and the Atbara are the ruling factors in flood, while the White Nile is the ruling factor during the remainder of the year.

18. — We have next to consider the times of rainfall. In the great lake regions the rainy season lasts from March to December with a maximum in August. At Gondokoro the rains continue from April to November with a maximum in August. In the valley of the Saubat the rainy season is from June to November with a maximum in August. It rains from April to September in the valley of the Gazelle River. From July to September is the rainy season at Khartoum, and from July to August in Kordofan and Darfûr. In Abyssinia, there are light rains in January and February and heavy rains from the middle of April to September with a maximum in August. August in the centre of heavy rainfall everywhere.

Time the water takes to reach Cairo from Lake Victoria.

19. — The time the water takes to travel down the different lengths of the river may be found from discharge, velocity and slope calculations, and from comparisons between the fluctuations of the Gondokoro. Khartoum, Assûan and Cairo gauges. I calculate that it takes the water 8 days to travel from Lake Victoria to Lake Albert, and five days from Lake Albert to Gondokoro. There is not much difference between high and low supply in these reaches. It takes the water 36 days to traverse the distance between Gondokoro and Khartoum in low supply, and 20 days in flood. Between Khartoum and Assûan the times are 26 days in low supply and 10 days in flood. Between Assûan and Cairo, we have 12 days in low supply and 5 days in flood; while between Cairo and the sea we have 3 days and 2 days respectively. It takes 90 days for the water in low supply to reach the sea from Lake Victoria, while in flood it takes 50 days.

20. — The Blue Nile traverses the distance between its sources and Khartoun in some 17 days in low supply, and 7 days in flood. The Atbara takes 5 days in flood and the Saubat cannot take a much longer time.

21. — Referring to the map and keeping all the above facts in mind, an average year in the Nile basin may be thus described. The heavy rains near Gondokoro begin in April and force down the green water of the swamp regions. About the 15th April, the White Nile at Gondokoro begins to rise, and by the 1st September has reached its maximum. In this interval the discharge has risen from 500 cubic metres per second to 1,600 cubic metres per second. This rise is felt at Khartoum about the 20th May and at Assûan about the 10th June. The green water announcing this rise is seen at Cairo about the 20th June. In an average year on the 20th May, the White Nile discharge of 300 cubic metres per second at Khartoum begins to increase, and goes on gradually increasing to the 15th or 20th September when the maximum floods of the White Nile and Saubat reach Khartoum and attain a discharge of 4,500 cubic metres per second. The low water discharge of the Blue Nile is 160 cubic metres per second and about the 5th June it begins to rise fairly quickly and reaches its ordinary maximum of 5,500 cubic metres per second by about the 25th August. Owing to the two floods rarely being contemporary the ordinary maximum flood of 8,000 cubic metres per second is generally on the 5th September. The red muddy water of the Blue Nile reaches Assûan about the 15th July and Cairo about the 25th July. Once the red water begins to appear the rise is rapid, for the Atbara is in flood shortly after the Blue Nile, and its flood waters rise with great rapidity. The Atbara would come down much earlier than its does were it not that a whole month is expended in saturating the desert and its own dry sandy bed. The Atbara flood begins in early part of July and is at its highest about the 20th August, reaching au ordinary maximum of 3,400 cubic metres per second and occasionally an extraordinary maximum of 4,900 cubic metres per second. **The Nile in flood.**

22. — It is owing to the earliness of the Atbara high flood and the lateness of the White Nile high flood, that the ordinary maximum discharge of the Nile at Assûan is only 10,000 cubic metres per second. This is generally on the 5th September. When the White Nile is weak, the maximum at Assûan is reached before or on the 5th September; when the White Nile is strong the maximum is reached about the 20th September. An early maximum as Assûan is always followed by a low summer, while a late maximum is nearly always followed by a high summer supply. Only once has this rule been broken and that was in 1891 when there were two maxima, one on the 4th September and another on the 27th. In this year there must have been an extraordinary fall of rain in Abyssinia in September, for the flood of the 27th September was very muddy, while as a rule the river at Assûan is very muddy in August, less so in September, and very much less so in October when the White Nile is the ruling factor in the supply of the river.

23. — If the White Nile happens to be in very heavy flood late in September, and the September rains in Abyssinia are also very heavy, an ordinary flood passes Assûan at the end of September and is disasterous for Egypt. This happened in 1878. Tables III and IV, contain details of this flood, of the minimum flood year 1877 and the mean of the 20 years from 1873 to 1892.

24. — At Assûan the Nile enters Egypt, and it now remains to consider it in its last 1,200 kilometres. The mean mininum discharge at Assûan in 410 cubic metres per second and is reached about the end of May. The river rises slowly till about the 20th July and then rapidly through August, reaching its maximum about the 5th September, and then falling very slowly through October and November. Table III, gives every detail of a maximum, minimum, and mean year. The deep perennial irrigation canals take water all the year round, but the flood irrigation canals are closed with earthen banks till the 15th August, and are the nall opened. These flood canals, of which there are some 45, are capable of discharging 2,000 cubic metres per second at the beginning of an ordinary year, 3,600 cubic metres per second in a maximum year, and have an immediate effect on the discharge of the Nile. The channel of the Nile itself and its numerous branches and arms consume a considerable

quantity of water (the cubic contents of the trough of the Nile between Assûan and Cairo are 7,000,000,000 cubic metres) the direct irrigation from the Nile between Assûan and Cairo takes 50 cubic metres per second, 130 cubic metres per second are lost by evaporation off the Nile, and 400 cubic metres per second by absorption. Owing to all these different causes, there is the net result that, from August 15th to October 1st, the Nile is discharging 2,400 cubic metres per second less at Cairo than at Assûan. During October and November the flood canals are closed, and the basins which have been filled in August and September discharge back into the Nile, and in October the Nile at Cairo is discharging 900 cubic metres per second in excess of the discharge at Assûan and 500 cubic metres per second in November. An examination of Tables II and III will show this very clearly.

25. — The ordinary minimum discharge at Cairo is 380 cubic metres per second and is attained on the 15th of June; the river rises slowly through July and fairly quickly in August, and reaches its ordinary maximum on the 1st October when there is no irrigation in the basins and the discharge from the basins is just beginning. The ordinary maximum discharge at Cairo is about 7,600 cubic metres per second. Through October the Nile at Cairo is practically stationary, and falls rapidly in November.

26. — North of Cairo are the heads of the perennial canals which irrigate the Delta proper. These canals, with their feeders lower down, discharge 1,200 cubic metres per second, and the ordinary maximum flood at Cairo of 7,600 cubic metres per second is reduced by this amount between Cairo and the sea. Of the 6,400 cubic metres per second which remain, 4,100 cubic metres per second find their way to the sea down the Rosetta branch, and 2,300 cubic metres per second down the Damietta branch. During extraordinary floods the Damietta branch has discharged 4,300 cubic metres per second and the Rosetta branch 7,000 cubic metres per second(1).

The Nile in low supply.

27. — We have so far considered the Nile in flood, it now remains to quickly dispose of the low supply. After reaching its maximum, the Atbara, which is a torrential river, falls more rapidly than others, and by the end of October has practically disappeared; after the middle of September the Blue Nile falls quickly, while the White Nile with its large basin, gentle flow and numerous reservoirs falls very deliberately. The mean discharge of the White Nile at Gondokoro in an ordinary year, at the time of low supply, is 550 cubic metres per second. By the time it reaches Khartoum it is reduced by evaporation to some 350 cubic metres per second. The ordinary low supply of the Blue Nile is 190 cubic metres per second, giving an ordinary low supply to the Nile at Khartoum of 540 cubic metres per second. The Atbara supplies nothing. Between Khartoum and Assûan there is a further loss from evaporation and irrigation of 130 cubic metres per second, and the mean low supply delivered at Assûan is 410 cubic metres per second. In very bad years the discharge at Assûan has fallen to 210 cubic metres per second, which would probably mean 340 cubic metres per second at Khartoum; and adopting Linant Pasha's proportion, the White Nile would be discharging 220 cubic metres per second and the Blue Nile 120 cubic metres per second. As the White Nile at Gondokoro never discharges much under 500 cubic metres per second, the loss on that river under the most unfavourable conditions is about 300 cubic metres per second, while the loss on the Blue Nile cannot be more than 50 cubic metres per second. Summing up therefore we may state in a very bad summer the Nile sources supply 660 cubic metres per second, the discharge at Khartoum has dwindled to 340 cubic metres per second and at Assûan to 210 cubic metres per second. The moment the daily fall of the

(1) The Barrage gauge is the upstream gauge of the Rosetta branch Barrage. Its zero is 10 metres above sea level and its mean low water level 11.00. Owing to the Nile here dividing into two branches this mean gauge is not capable of reference to other gauges on the Nile as it is affected by the bifurcation.

river becomes less than the daily loss by evaporation, all the small ponds and pools cease to aid the stream, and if they are very extensive, as they are South of Fashoda, they diminish the discharge considerably by their large evaporating areas. The six cataracts of the Nile with their numerous raised sills moderate floods and lengthen them out, but when the two months of real low discharge have come, the great reservoirs of the Nile are the sole sources of supply.

28. — As Egypt possesses no barometric, thermometric, or rain gauge stations in the valley of the Nile, we are always ignorant of the coming flood, though famine years in India are generally years of low flood in Egypt. If however the summer supply of the Nile has been exceedingly low and exceedingly late, we anticipate a high flood following it, as the drought in the valley of the White Nile must create a powerful draught on the Indian Ocean. Again, as to the summer supply, we generally anticipate a poor volume in the river at that season, if the preceeding Nile flood at Assûan has been early; and a good supply if the flood at Assûan has been late. Between Assûan and Cairo, previous to 1890, we had little control over the flood since the canals and escapes in Upper Egypt had no masonry regulating works and the Nile in high flood did very much what it liked. Since 1890 however, the Public Works Department has constructed 90 important regulating works, and by proper manipulation we can now fairly control a high flood by using the canals and escapes so as not to let the Nile at Cairo rise much above 4.8 metres, which is the maximum gauge the banks on the Damietta branch can support with any degree of security. It was mainly owing to this power of control that the excessive and late flood of 1892 passed through Egypt without causing any real damage, **Anticipation of flood and low supply.**

29. — When we consider the energy and the self-denying labours of the men who achieved the great discoveries of the source of the Nile, it seems but a poor compensation to them to know that these sources can now be depicted on the plans. It would be a triumph indeed and a real compensation if the resources of modern science could be employed to utilise these great lakes, and, by the construction of suitable works, insure a constant and plentiful supply of water to the Nile valley during the summer months when water is scarce and as valuable as gold. Both the Victoria (1) and the Albert lakes lend themselves to be utilised as reservoirs as they have rocky sills at their outlets, while the Albert and Tsana lakes by their convenient size are eminently suited for regulating basins. The day these works are carried out at the sources of the Nile, the lakes will take their proper place in the economy of the water supply, and we shall be able to say of them in their entirety, as we can say of them to-day in their degree, that what the snows of the Alps are to the Po, Lakes Victoria, Nyanza at Tsana are to the Nile, and what the Italian lakes are to the plains of Lombardy, Lake Albert is to the land of Egypt. **The sources of the Nile.**

30. — The following tables follow this report: — **The Tables.**

Table I. — Discharge table for the Assûan, Assiout and Cairo gauges.
Table II. — Five daily gauges and discharges at Assûan and Cairo for the maximum, minimum and mean years.
Table III. — Five daily gauges and discharges at Assûan, Assiout and Cairo for 1892 and 1893.
Table IV. — Discharges of the Upper Egypt canals in the flood of 1892.
Table V. — Discharges of the Upper Egypt canals in the flood of 1893.
Table VI. — Assûan and Cairo gauge readings 1893 and 1892.
Table VII. — Discharge table of the Upper Egypt canals.

(1) The English Foreign Office has been asked to erect and read a gauge on Lake Victoria so that we may compare the gauge readings at Lake Victoria with the summer discharge of the Nile at Assuân.

31. — With respect to the first three tables it should be borne in mind that it is impossible to find a table giving exact discharges for any given gauge at any given time, but the above tables give the means of hundreds of observations. A rising Nile discharges more for a giving gauge than a falling Nile, and again high flood scours its bed and a low flood slits it up. Indeed it is owing to the fact that the low floods are more numerous than the high floods, that the silting process gains on the scouring out and we have rise of the bed per century (as seen in paras 10 and 12). A rise of the bed is accompanied with a rise of the general level of the Nile valley where there is basin irrigation.

TABLE I.

Discharge tables for the Assuân, Assiout and Cairo gauges.

The gauges are in metres and are referred to mean low water level as zero. This zero is

at Assuân............... R. L. 85.00
at Assiout............... R. L. 45.55
at Cairo................. R. L. 12.25

N. B. — (At Assiout R. L. 45.55 according to the reservoir levels is R. L. 45.05 according to the 4th Circle levels).

(The discharges are in cubic metres per second).

Discharge table of the Assuân, Assiout and Cairo gauges, which may be used approximately (1) for any gauge on the Nile north of Assuân with its zero at mean low water level.

GAUGE	DISCHARGE	GAUGE	DISCHARGE	GAUGE	DISCHARGE	GAUGE	DISCHARGE
— 1.0	150	2.0	1390	5.0	4350	8.0	9800
— .9	170	.1	1460	.1	4500	.1	10050
— .8	190	.2	1530	.2	4650	.2	10300
— .7	210	.3	1580	.3	4800	.3	10600
— .6	230	.4	1650	.4	4950	.4	10900
— .5	260	.5	1720	.5	5100	.5	11200
— .4	290	.6	1800	.6	5250	.6	11500
— .3	320	.7	1880	.7	5400	.7	11800
— .2	350	.8	1960	.8	5550	.8	12100
— .1	380	.9	2050	.9	5700	.9	12500
0.0	410	3.0	2130	6.0	5850	9.0	12800
.1	450	.1	2210	.1	6000	.1	13200
.2	490	.2	2300	.2	6150	..	..
.3	530	.3	2400	.3	6300	..	..
.4	570	.4	2500	.4	6450	..	..
.5	610	.5	2600	.5	6600	..	..
.6	650	.6	2700	.6	6800	..	..
.7	690	.7	2800	.7	7000	..	..
.8	730	.8	2900	.8	7200	..	..
.9	780	.9	3000	.9	7400	..	..
1.0	830	4.0	3100	7.0	7600	..	..
.1	880	.1	3200	.1	7800	..	..
.2	930	.2	3300	.2	8000	..	..
.3	980	.3	3400	.3	8200	..	..
.4	1030	.4	3500	.4	8400	..	..
.5	1080	.5	3600	.5	8600	..	..
.6	1140	.6	3750	.6	8800	..	..
.7	1200	.7	3900	.7	9050	..	..
.8	1260	.8	4050	.8	9300	..	..
.9	1320	.9	4200	.9	9550	..	..

(1) See tables IX and X when it will be seen that these discharges are too high for the reach of the Nile from Silsila to Kasr-es-Saâd north of Kena.

TABLE II.

Five daily gauges and discharges at Assuân and Cairo for the minimum and maximum years, and the mean of 20 years

DATE	MINIMUM YEAR 1877/78				MAXIMUM YEAR 1878-79				MEAN OF 20 YEARS			
	ASSUAN		CAIRO		ASSUAN		CAIRO		ASSUAN		CAIRO	
	Gauge	Discharge	Gauge	Discharge	Gauge	Discharge	Gauge	Discharge	Gauge	Discharge	Gauge	Discharge
June.......... 5	.2	[illegible]	.7	490	—.7	210	0	180	.1	450	.9	[illegible]
10	.4	570	.7	450	—.7	210	0	180	.2	[illegible]	.9	390
15	.8	730	.7	490	—.7	210	0	170	.4	570	.9	380
20	1.0	830	.8	530	—.6	230	—.2	170	.5	610	.9	400
25	1.0	830	1.0	610	—.3	320	—.2	160	.7	690	1.0	420
30	1.1	880	1.3	780	—.6	650	—.2	160	1.1	880	1.1	480
July........... 5	1.8	1260	1.2	780	.9	780	—.2	170	1.4	1030	1.1	550
10	2.1	1460	1.2	830	1.1	880	.4	300	1.8	1260	1.3	700
15	3.2	2300	1.4	1000	1.4	1030	.8	500	2.3	1580	1.5	850
20	3.2	2300	1.6	1200	2.5	1720	1.0	700	2.9	2050	1.8	1000
25	3.7	2800	2.4	1600	3.8	2900	1.4	950	3.7	2800	2.2	1200
31	4.7	4050	2.8	2000	5.2	4800	2.6	1880	5.0	4500	2.9	1800
August........ 5	4.8	4200	3.6	2700	5.6	5100	4.1	3200	5.7	5550	4.1	3200
10	5.4	5100	4.0	3100	6.3	6450	4.9	4200	6.6	7000	4.9	4200
15	5.8	5700	4.7	3900	7.2	8200	5.4	5100	7.0	7800	5.7	5550
20	6.4	6150	4.6	3750	7.5	8600	6.0	6000	7.3	8400	5.9	5850
25	6.1	5850	5.3	4800	8.1	10050	6.3	6450	7.6	9050	6.2	6300
31	6.2	6000	5.3	4800	7.6	8800	6.6	6800	7.8	9550	6.4	6600
September.... 5	6.3	6150	5.2	4500	8.1	10300	6.5	6600	7.9	9800	6.5	6800
10	6.1	5850	5.3	4650	8.5	11500	6.8	7400	7.9	9800	6.7	7000
15	6.0	5700	5.2	4500	8.9	12800	7.2	[illegible]	7.9	9800	6.8	7200
20	6.0	5700	5.2	4500	8.9	12500	7.6	9050	7.7	8800	6.9	7400
25	6.3	6150	5.1	4350	9.0	12800	7.9	9800	7.6	8600	7.0	[illegible]
30	6.1	5850	5.3	4650	9.1	**13200**	8.2	10600	7.4	8200	7.0	7400
October 5	5.6	5100	5.2	4500	8.9	12100	8.4	11200	7.0	7400	6.9	7200
10	5.2	4500	5.0	4250	8.5	10900	8.7	11900	6.7	6800	6.9	7200
15	4.9	4200	4.9	4200	7.9	9300	8.3	10300	6.3	6150	6.8	7000
20	4.6	3750	4.6	3750	7.6	8600	8.1	10050	6.0	5700	6.8	7000
25	4.5	3600	4.4	3500	7.4	8200	7.9	9300	5.7	5250	6.7	6800
31	4.0	3100	4.2	3300	6.8	7000	7.7	8800	5.2	4650	6.2	6000
November 5	3.7	2800	3.9	3000	6.3	6150	7.5	8400	4.8	4050	5.6	5100
10	3.6	2700	3.6	2700	6.9	5550	7.4	8200	4.5	3600	5.1	4350
15	3.4	2500	3.7	2800	5.5	4950	6.9	7200	4.2	3300	4.7	3900
20	3.2	2300	3.7	2700	5.2	4500	6.2	6000	4.0	3100	4.3	3300
25	2.9	2050	3.5	2300	4.9	4200	5.5	4950	3.8	2900	4.0	3000
30	2.7	1880	3.1	2000	4.7	3900	5.5	4950	3.6	2700	3.8	2800
December 5	2.5	1720	2.9	1720	4.5	3600	4.9	4200	3.4	2500	3.6	2600
10	2.4	1650	2.7	1650	4.4	3500	4.7	3900	3.2	2300	3.4	2400
15	2.2	1530	2.6	1530	4.2	3300	4.5	3600	3.1	2210	3.3	2300
20	2.1	1460	2.5	1460	4.1	3200	4.4	3500	3.0	2130	3.2	2210
25	2.0	1390	2.4	1390	3.9	3000	4.2	3300	2.9	2050	3.0	2130
31	2.0	1390	2.3	1390	3.8	[illegible]	4.0	3100	2.7	1880	2.9	1960
January....... 5	1.9	1320	2.2	1320	3.6	2700	3.7	2800	2.6	1880	2.8	1880
10	1.8	1260	2.1	1260	3.5	2600	3.6	2700	2.5	1720	2.7	1720
15	1.6	1140	2.2	1140	3.4	2500	3.5	2600	2.3	1580	2.6	1580
20	1.5	1080	1.9	1080	3.3	2400	3.4	2500	2.2	1530	2.5	1530
25	1.4	1030	1.8	1030	3.2	2300	3.3	2400	2.1	1460	2.4	1460
30	1.2	930	1.7	930	3.1	2210	3.2	2300	2.0	1390	2.3	1390
February 5	1.1	880	1.6	880	3.1	2210	3.2	2210	1.9	1320	2.2	1320
10	.9	780	1.5	780	3.0	2130	3.0	2130	1.7	1200	2.2	1200
15	.8	730	1.3	730	2.9	2050	2.9	2050	1.6	1140	2.1	1140
20	.7	690	1.2	690	2.8	1960	2.9	1960	1.5	1080	2.0	1080
25	.5	610	1.1	610	2.8	1960	2.8	1960	1.4	1030	1.9	1030
28	.5	610	1.1	610	2.7	1880	2.8	1880	1.3	980	1.9	980
March......... 5	.3	530	1.0	530	2.7	1880	2.7	1880	1.2	930	1.8	930
10	.2	490	.9	490	2.7	1880	2.7	1880	1.1	880	1.8	880
15	.2	490	.9	490	2.6	1800	2.6	1800	1.0	830	1.7	830
20	.1	450	1.0	450	2.6	1800	2.6	1800	.9	780	1.6	780
25	.0	410	.8	410	3.5	1720	2.5	1720	.8	730	1.6	730
30	—.1	380	.8	380	2.5	1720	2.5	1720	.6	650	1.5	650
April.......... 5	—.1	380	.6	380	2.4	1650	2.5	1650	.5	610	1.5	610
10	—.2	350	.6	350	2.3	1580	2.5	1580	.4	570	1.4	570
15	—.3	320	.5	320	2.2	1530	2.5	1530	.4	570	1.3	570
20	—.3	320	.5	320	2.2	1530	2.4	1530	.3	530	1.3	530
25	—.4	290	.4	290	2.3	1580	2.3	1530	.3	530	1.2	530
30	—.4	290	.3	290	2.2	1530	2.3	1530	.2	490	1.2	490
May 5	—.5	260	.3	260	2.2	1530	2.2	1530	.2	490	1.1	490
10	—.5	260	.2	250	2.0	1390	2.2	1390	.1	450	1.1	450
15	—.5	260	.2	230	2.0	1390	2.2	1390	.1	450	1.1	450
20	—.6	230	.2	220	1.9	1320	2.1	1320	0.0	410	1.1	410
25	—.6	230	.1	200	2.0	1390	2.1	1320	0.0	410	1.0	410
31	—.6	230	.0	190	2.2	1530	2.0	1320	.1	450	1.0	410

TABLE II [*continued*].

Mean monthly gauges and discharges at Assuân and Cairo for the maximum and minimum years, and the mean of 20 years.

MONTH	MINIMUM YEAR 1877/78				MAXIMUM YEAR 1878/79				MEAN OF 20 YEARS			
	ASSUAN		CAIRO		ASSUAN		CAIRO		ASSUAN		CAIRO	
	Gauge	Discharge	Gauge	Discharge	Gauge	Discharge	Gauge	Discharge	Gauge	Discharge	Gauge	Discharge
June	.8	720	.4	560	—.4	300	—.9	170	.5	600	0.0	410
July	3.3	2360	1.4	1030	2.9	2020	.8	750	3.1	2200	1.4	1010
August	5.8	5550	4.6	3840	7.1	7910	5.6	5290	7.1	7930	5.6	5280
September	6.1	5900	5.1	4520	8.8	12180	7.5	8600	7.7	9170	6.8	7200
October	4.8	4040	4.7	3910	7.8	9350	8.2	10250	6.1	5990	6.6	6860
November	3.3	2370	3.4	2550	5.4	4870	6.5	6610	4.2	3270	4.6	3740
December	2.2	1520	2.2	1520	4.2	3250	4.5	3600	3.0	2180	3.1	2260
January	1.6	1120	1.7	1220	3.3	2450	3.4	2550	2.3	1590	2.3	1590
February	.7	710	.8	710	2.9	2030	2.9	2030	1.6	1120	1.6	1120
March	.1	450	.1	450	2.6	1800	2.6	1800	.9	800	.9	800
April	—.3	320	—.3	320	2.2	1560	2.2	1560	.3	550	.3	550
May	—.6.	240	—.7	220	2.1	1420	2.0	1370	.1	440	1	430
Year	3.0	2'00	2.5	1730	4.8	4090	4.6	3710	3.9	2990	3.5	2610
		370				380				370		

TABLE III.

Five daily gauges and discharges at Assuân, Assiout and Cairo for 1892 and 1893.

DATE		1892						1893					
		ASSUAN		ASSIOUT		CAIRO		ASSUAN		ASSIOUT		CAIRO	
		Gauge	Discharge	Gauge	Discharge	Gauge	Discharge	Gauge	Discharge	Gauge	Discharge	Gauge	Discharge
January	5	2.6	1800	2.7	1880	2.7	1880	3.2	2300	3.0	2210	3.0	2300
	10	2.5	1720	2.5	1720	2.6	1800	3.1	2210	2.9	2130	3.0	2210
	15	2.4	1650	2.4	1650	2.4	1650	3.0	2130	2.8	2020	2.9	2130
	20	2.3	1580	2.3	1580	2.3	1580	2.9	2050	2.7	1880	2.8	2050
	25	2.2	1530	2.2	1530	2.2	1530	2.8	1960	2.6	1880	2.7	1960
	31	2.0	1390	2.1	1460	2.1	1460	2.8	1960	2.5	1880	2.5	1960
February	5	1.9	1320	2.0	1320	2.0	1320	2.8	1960	2.5	1880	2.5	1960
	10	1.7	1200	1.9	1200	2.1	1200	2.7	1880	2.5	1800	2.5	1880
	15	1.6	1140	1.7	1140	2.0	1140	2.6	1800	2.4	1720	2.5	1800
	20	1.4	1030	1.6	1030	2.0	1030	2.6	1800	2.3	1720	2.4	1800
	25	1.2	930	1.4	930	1.9	930	2.5	1720	2.3	1650	2.5	1720
	28	1.0	830	1.3	830	1.9	830	2.4	1650	2.2	1580	2.5	1650
March	5	.9	780	1.1	780	1.8	780	2.4	1650	2.2	1580	2.5	1650
	10	.8	730	1.0	730	1.7	730	2.3	1580	2.1	1570	2.3	1580
	15	.6	650	.9	650	1.7	650	2.3	1580	2.0	1530	2.2	1580
	20	.5	610	.8	610	1.7	610	2.3	1580	2.0	1530	2.2	1580
	25	.4	570	.6	570	1.6	570	2.3	1580	2.0	1530	2.2	1580
	31	.3	530	.5	530	1.8	530	2.2	1530	2.0	1460	2.2	1530
April	5	.2	490	.5	490	1.8	490	2.2	1530	1.9	1460	2.2	1530
	10	.0	410	.3	410	1.8	410	2.3	1580	2.0	1530	2.2	1530
	15	—.1	380	.2	380	1.8	380	2.2	1530	2.0	1530	2.2	1530
	20	—.1	380	.1	380	1.7	380	2.0	1390	1.9	1390	2.2	1390
	25	—.2	350	.0	350	1.7	350	1.8	1260	1.7	1260	2.1	1260
	30	—.3	320	—.1	320	1.8	320	1.5	1080	1.5	1080	1.8	1080
May	5	—.4	290	—.2	290	1.7	290	1.3	980	1.3	980	2.0	980
	10	—.4	290	—.2	290	1.7	290	1.1	880	1.1	880	1.9	880
	15	—.4	290	—.3	290	1.7	290	.9	780	.9	780	1.9	780
	20	—.5	260	—.3	290	1.7	290	.7	690	.7	690	1.8	690
	25	—.4	290	—.4	260	1.5	280	.7	690	.6	690	1.8	690
	31	—.6	230	—.4	260	1.4	280	.6	650	.5	650	1.7	650
June	5	—.6	230	—.5	230	1.4	280	.5	610	.4	610	1.7	610
	10	—.5	250	—.5	230	1.4	260	.4	570	.4	570	1.9	570
	15	—.5	270	—.5	230	1.3	230	.4	530	.3	530	1.9	530
	20	—.4	300	—.4	260	1.2	230	.4	570	.2	530	1.9	530
	25	—.2	350	—.4	270	1.3	250	.5	610	.1	520	1.8	5 0
	30	.2	490	—.4	300	1.3	270	.6	650	.2	520	1.8	530
July	5	.6	650	—.2	350	1.4	300	.8	730	.2	570	1.8	530
	10	1.0	830	.2	490	1.6	400	1.1	880	.4	610	1.8	530
	15	1.6	1180	.5	610	1.7	500	1.4	1030	.6	690	1.9	570
	20	2.4	1650	1.2	930	2.1	700	2.2	1530	.9	780	2.1	630
	25	3.8	2900	1.9	1320	2.2	900	2.8	1960	1.5	1000	2.2	730
	31	5.4	5050	3.4	2500	2.7	1200	5.4	5100	2.6	1800	2.4	1200
August	5	6.3	6450	5.2	4800	3.9	3000	6.0	6000	4.7	3900	3.5	2600
	10	6.8	7400	5.7	5550	5.3	4950	7.0	7600	5.6	5400	4.9	4200
	15	6.7	7000	5.8	5550	5.8	5550	7.0	7800	6.0	5850	5.7	5400
	20	7.4	8600	5.8	5550	5.4	4950	7.4	8600	6.0	5850	5.5	5100
	25	8.3	10900	6.5	6450	5.8	5700	7.5	8600	6.2	6150	5.8	5550
	31	8.3	10900	7.1	8000	6.6	7000	7.4	8400	6.2	6150	5.9	5700
September	5	8.6	11800	7.2	8200	6.9	7400	7.3	8200	6.0	5850	5.9	5700
	10	8.8	12500	7.5	8800	7.1	8000	7.4	8400	6.1	6000	5.7	5400
	15	8.8	12500	8.0	10050	7.3	8800	7.6	8800	6.4	6450	5.8	5550
	20	8.9	12800	8.1	10050	7.9	9800	7.5	8600	6.3	6300	5.9	5700
	25	8.7	11500	8.2	10300	8.1	10300	7.5	8600	6.4	6450	6.0	5850
	30	8.4	10600	8.1	9800	8.3	10900	7.3	8200	6.5	6600	6.2	6150
October	5	8.2	10050	7.9	9300	8.4	10900	7.1	7800	6.3	6300	6.1	6000
	10	7.8	9050	7.8	9050	8.3	10300	7.4	8400	6.3	6300	6.0	5850
	15	7.4	8200	7.5	8400	8.1	9800	7.0	7400	6.6	6800	6.3	6300
	20	7.2	7800	7.4	8200	7.9	9300	6.5	6450	6.5	6900	6.4	6450
	25	6.8	7000	7.1	7600	7.9	9300	6.0	5700	6.6	6800	7.1	8000
	31	6.3	6150	6.5	6450	7.8	9050	5.6	5100	6.1	5850	6.9	7200
November	5	5.7	5250	5.9	5550	7.2	7800	..	..	..	..	..	..
	10	5.3	4650	5.3	4650	6.4	6300	..	..	..	..	..	..
	15	5.0	4200	4.9	4200	5.6	5100	..	..	..	..	..	..
	20	4.6	3750	4.6	3750	4.8	4050	..	..	..	..	..	..
	25	4.4	3500	4.3	3400	4.4	3500	..	..	..	..	..	..
	30	4.1	3200	4.1	3200	4.2	3300	..	..	..	..	..	..
December	5	3.9	3000	3.8	2900	3.9	3000	..	..	..	..	..	..
	10	3.8	2900	3.6	2700	3.7	2800	..	..	..	..	..	..
	15	3.6	2700	3.5	2600	3.5	2600	..	..	..	..	..	..
	20	3.5	2600	3.4	2500	3.3	2500	..	..	..	..	..	..
	25	3.4	2500	3.2	2300	3.2	2400	..	..	..	..	..	..
	31	3.3	2400	3.1	2210	3.1	2300	..	..	..	..	..	..

TABLE III [*continued*].

Mean monthly gauges and discharges at Assuân, Assiout and Cairo for 1892 and 1893.

MONTH	1892						1893					
	ASSUAN		ASSIOUT		CAIRO		ASSUAN		ASSIOUT		CAIRO	
	Gauge	Discharge	Gauge	Discharge	Gauge	Discharge	Gauge	Discharge	Gauge	Discharge	Gauge	Discharge
January	2.4	1610	2.4	1630	2.4	1650	3.0	2100	2.8	2000	3.0	2100
February	1.5	1070	1.5	1070	1.5	1070	2.6	1800	2.5	1720	2.6	1800
March	.6	640	.6	640	.6	640	2.3	1580	2.2	1520	2.3	1580
April	— 1	390	—.1	390	—.1	380	2.0	1380	1.9	1340	2.0	1380
May	—.5	270	—.5	280	—.5	280	.9	780	.9	780	.9	780
June	—.3	310	—.5	250	—.5	250	.4	590	.3	550	.3	550
July	2.9	2040	1.4	1030	.6	660	2.7	1870	1.1	900	.7	690
August	7.4	8540	6.1	5980	5.5	5190	7.1	7830	5.8	5550	5.3	4760
September	8.7	11950	7.8	9530	7.7	9200	7.4	8470	6.3	6270	5.9	5720
October	7.2	8040	7.3	8160	8.0	9860	6.6	6800	6.4	6440	6.5	6630
November	4.8	4090	4.8	4120	5.4	5000	..	..	..	..	..	..
December	3.6	2680	3.4	2530	3.5	2600	..	..	..	..	..	..
Year	4.4	3470	3.9	2960	4.0	3060	..	..	..	..	..	..

TABLE IV.

Discharges of the Canal in Upper Egypt in 1892.

Canal discharges between Assuân and Assiout.

NAME OF CANAL	AUGUST				SEPTEMBER					
	15	20	25	31	5	10	15	20	25	30
Ramadi	55	66	80	76	82	85	89	91	..	..
Um-Ads	8	9	12	13	16	18	20	..	..	..
Afsûn	25	29	37	39	42	43	45	..	..	..
Fadilie	12	26	44	49	52	55	50	..	..	..
Toukh	10	19	37	42	44	58	60	..	..	..
Rannan	28	[illegible]	53	59	62	67	70	..	..	..
Dumrania	26	35	56	62	65	70	74	..	..	..
Rashwania	35	41	58	61	64	70	73	..	..	..
Kasra	49	62	104	133	138	150	150	..	..	..
Zarzria	24	30	64	76	77	90	90	..	..	..
Girgawia	54	59	84	95	96	120	120	..	..	..
Sobagia	380	386	470	485	492	520	500	..	..	..
Tahta	44	45	66	75	77	82	85	..	..	..
Shatura	25	24	39	47	49	45	40	..	..	..
Ibrahimia	460	440	540	609	640	700	740	..	..	..
Waladia	6	6	14	20	24	24	24	..	..	..
Minor Canals	10	15	20	30	30	30	20	..	..	..
TOTAL LEFT BANK	1250	1320	1790	1980	2060	2250	2270	..	..	..
Kilibia	6	11	17	20	24	28	32	..	..	..
Maala	5	5	18	22	26	30	32	..	..	..
Bayadiâ	30	36	62	69	77	85	90	..	..	..
Shanhuria	46	55	98	108	116	120	125	..	..	..
Shekha	5	6	10	11	12	12	12	..	..	..
Gilasi	19	30	58	64	68	70	72	..	..	..
Samatha	12	19	41	48	52	60	60	..	..	..
Tarif	10	15	20	25	25	25	25	..	..	..
Hawis	15	22	38	41	44	51	56	..	..	..
Ahaiwia	10	15	20	25	25	25	25	..	..	..
Isaiwia	35	35	55	60	63	70	70	..	..	..
Khizindaria	63	62	86	96	98	110	95	..	..	..
Maanah	35	41	58	67	71	80	85	..	..	..
Sant	6	7	8	10	10	12	12	..	..	..
Minor Canals	4	8	12	15	15	15	15	..	..	..
TOTAL RIGHT BANK	300	370	600	680	730	800	810	..	..	..
TOTAL BOTH BANKS	1550	1690	2390	2660	2790	3050	3080	..	..	..

Canal discharges between Assiout and Cairo.

NAME OF CANAL	Aug. 15	Aug. 20	Aug. 25	Aug. 31	Sept. 5	Sept. 10	Sept. 15	Sept. 20	Sept. 25	Sept. 30
Beni-Husain	13	16	20	30	35	40	..	..	..	..
Abu-Bakra	53	38	60	80	85	93	..	..	..	..
Sultani	18	10	20	37	38	40	..	..	..	..
Nina	9	5	10	20	20	20	..	..	..	..
Bahabshin	12	8	14	27	28	33	..	..	..	..
Magnuna	15	15	22	40	45	45	..	..	..	..
Kushesha	70	70	70	70	70	70	..	..	..	..
Zawia	11	7	16	27	28	33	..	..	..	..
Girza	40	38	70	95	100	100	..	..	..	..
Zumr	13	12	14	19	20	19	..	..	..	..
Minor Canals	2	2	4	4	4	4	..	..	..	..
TOTAL LEFT BANK	260	220	320	450	480	500	..	..	..	..
Aly Bey	14	13	28	33	20	18	..	..	..	..
Khassâb	19	14	25	35	40	46	..	..	..	..
Minor Canals	7	6	12	12	14	14	..	..	..	..
TOTAL RIGHT BANK	40	30	70	80	80	80	..	..	..	..
TOTAL BOTH BANKS	300	250	390	530	560	580	..	..	..	..

Canal discharges between Assuân and Cairo.

NAME OF CANAL	Aug. 15	Aug. 20	Aug. 25	Aug. 31	Sept. 5	Sept. 10	Sept. 15	Sept. 20	Sept. 25	Sept. 30
Left bank	1510	1540	2110	2430	2540	2750	..	..	..	..
Right bank	340	400	670	760	810	880	..	..	..	..
TOTAL	1850	1940	2780	3190	3390	3630	..	..	..	..
Assuân gauge	6.7	7.4	8.3	8.3	8.6	8.8	8.7	..	..	..
Assiout gauge	6.1	5.9	6.8	7.2	7.4	7.7	8.1	..	..	..
Cairo gauge	5.8	5.5	5.8	6.7	7.0	7.2	7.7	..	..	..

TABLE V.

Discharges of the Canals in Upper Egypt in 1893.

Canal discharges between Assuân and Assiout.

NAME OF CANAL	AUGUST				SEPTEMBER						OCTOBER				
	15	20	25	31	5	10	15	20	25	30	5	10	15	20	25
Ramadi	50	56	58	56	55	60	64	61	64	61	..	..	..	..	..
Um-Ads	10	12	12	12	13	14	15	15	15	15	..	..	..	..	..
Asfun	28	33	34	33	31	33	35	33	34	33	..	..	..	..	..
Fadilia	17	24	26	26	22	24	29	24	22	20	..	..	..	..	..
Toukh	19	24	25	27	21	24	24	22	27	26	..	..	..	..	..
Rannan	20	26	29	28	25	25	30	27	30	28	..	..	..	..	..
Dumrania	33	39	44	43	30	41	46	43	46	44	..	..	..	..	..
Rashwavia	45	52	60	55	50	53	68	60	65	60	..	..	..	..	..
Kasra	70	72	82	79	72	76	87	82	87	82	..	..	..	..	..
Zarzuria	38	44	47	46	45	47	52	46	52	46	..	..	..	..	..
Gergawia	55	55	59	58	56	56	62	57	62	57	..	..	..	..	..
Sohagia	390	380	400	390	350	360	420	390	430	410	..	..	..	..	..
Tahta	45	46	47	46	44	45	51	44	52	47	..	..	..	..	..
Shatura	20	23	26	25	22	17	28	25	29	28	..	..	..	..	..
Ibrahimia	520	520	560	560	540	540	600	580	600	600	..	..	..	..	..
Waladia	10	11	12	12	11	11	11	12	12	12	..	..	..	..	..
Minor Canals	10	15	20	20	20	20	20	20	20	20	..	..	..	..	..
TOTAL LEFT BANK	1380	1430	1550	1510	1420	1440	1640	1540	1650	1590	..	..	..	..	..
Kilibia	11	13	15	14	14	15	17	16	16	16	..	..	..	..	..
Maala	11	12	13	12	13	14	16	16	16	16	..	..	..	..	..
Bayadia	36	44	48	46	40	45	52	44	42	30	..	..	..	..	..
Shanhuria	56	64	69	63	62	64	70	50	40	30	..	..	..	..	..
Shekhia	6	7	9	8	6	6	4	5	6	6	..	..	..	..	..
Gilasi	24	32	34	32	29	30	35	31	34	33	..	..	..	..	..
Samatha	17	24	27	25	22	24	28	25	27	26	..	..	..	..	..
Tarif	12	14	16	15	14	15	17	16	17	16	..	..	..	..	..
Hawis	24	27	29	29	27	27	29	27	25	16	..	..	..	..	..
Ahaiwia	15	16	16	16	12	12	10	7	4	4	..	..	..	..	..
Isawia	30	37	40	37	37	39	40	40	43	40	..	..	..	..	..
Khazindaria	60	62	67	66	60	60	66	65	55	50	..	..	..	..	..
Maanah	29	30	32	32	29	32	33	34	24	24	..	..	..	..	..
Sant	6	6	9	8	7	7	7	7	7	7	..	..	..	..	..
Minor Canals	4	7	10	10	10	10	10	10	10	10	..	..	..	..	..
TOTAL RIGHT BANK	340	400	430	410	390	400	430	390	370	320	..	..	..	..	..
TOTAL BOTH BANKS	1720	1830	1980	1920	1810	1840	2070	1930	2020	1910	..	..	..	..	..

Canal discharges between Assiout and Cairo.

Beni Husain	17	18	19	20	14	12	16	17	17	17	..	..	..	..	..
Abu-Bakra	63	50	63	64	60	58	68	65	64	64	..	..	..	..	..
Sultani	17	16	17	17	16	15	17	17	17	17	..	..	..	..	..
Nina	9	8	9	10	10	9	9	9	9	9	..	..	..	..	..
Bahabshin	11	9	11	12	12	10	12	11	13	14	..	..	..	..	..
Magnuna	21	20	20	20	24	23	28	29	30	30	..	..	..	..	..
Kushàska	70	70	50	30	0	0	0	0	0	0	..	..	..	..	..
Zawia	11	8	13	12	13	12	13	15	16	17	..	..	..	..	..
Girza	50	45	50	55	60	60	50	50	40	30	..	..	..	..	..
Zumr	10	10	10	10	6	6	7	12	14	15	..	..	..	..	..
Minor Canals	2	2	2	2	2	2	2	2	2	2	..	..	..	..	..
TOTAL LEFT BANK	280	260	270	250	220	210	220	220	220	220	..	..	..	..	..
Ali bey	16	20	27	28	15	12	15	17	20	20	..	..	..	..	..
Khassàh	20	20	20	22	19	15	19	15	15	18	..	..	..	..	..
Minor Canals	6	6	6	6	7	7	7	7	7	7	..	..	..	..	..
TOTAL RIGHT BANK	40	50	50	60	40	30	40	40	40	50	..	..	..	..	..
TOTAL BOTH BANKS	320	310	310	310	260	240	260	260	260	270	..	..	..	..	..

Canal discharges between Assuân and Cairo.

Left bank	1660	1690	1810	1760	1640	1650	1960	1760	1870	1810	..	..	..	..	..
Right bank	380	450	480	470	430	430	470	430	410	370	..	..	..	..	..
TOTAL	2040	2140	2290	2230	2070	2080	2330	2190	2280	2180	..	..	..	..	..
Assuân gauge	7.0	7.3	7.4	7.3	7.2	7.5	7.6	7.4	7.1	7.3	7.1	7.3	6.9	6.3	6.0
Assiout gauge	6.2	6.2	6.4	6.3	6.2	6.3	6.5	6.5	6.6	6.6	6.4	6.5	6.7	6.7	..
Cairo gauge	5.8	5.6	5.9	6.0	6.0	5.8	6.0	6.0	6.1	6.3	6.2	6.1	6.4	6.5	2.7

TABLE VI.

Assuân and Cairo gauge readings from 1873 to 1892.

YEARS	1873		1874		1875		1876		1877		1878		1879	
DATES	Assuân	Cairo	Assuân	Cairo	Assuân	Cairo	Assuân	Cairo	Assuân	Cairo	Assuân	Cairo	Assuân	Cairo
January.. 5	2.9	3.7	2.0	2.6	3.0	3.2	2.7	3.0	2.4	2.7	1.9	2.2	3.6	3.7
10	2.8	3.5	1.8	2.4	2.8	3.1	2.7	2.9	2.3	2.7	1.8	2.1	3.5	3.6
15	2.7	3.5	1.6	2.2	2.7	2.9	2.6	2.8	2.2	2.6	1.6	2.1	3.4	3.5
20	2.5	3.3	1.4	2.1	2.6	2.9	2.5	2.8	2.0	2.6	1.5	1.9	3.3	3.4
25	2.5	3.1	1.2	2.0	2.5	2.8	2.4	2.6	1.9	2.5	1.4	1.8	3.2	3.3
31	2.4	2.8	1.0	1.9	2.4	2.7	2.4	2.6	1.7	2.3	1.2	1.7	3.1	3.2
February. 5	2.3	2.9	0.8	1.9	2.3	2.6	2.3	2.5	1.6	2.2	1.1	1.6	3.1	3.2
10	2.4	2.7	0.7	1.8	2.2	2.5	2.2	2.5	1.5	2.1	0.9	1.5	3.0	3.0
15	2.3	2.7	0.6	1.7	2.0	2.5	2.2	2.5	1.3	1.9	0.8	1.3	2.9	2.9
20	2.2	2.5	0.4	1.6	1.9	2.4	2.2	2.4	1.2	1.8	0.7	1.2	2.8	2.9
25	2.1	2.3	0.4	1.5	1.8	2.3	2.1	2.3	1.1	1.7	0.5	1.1	2.8	2.8
28	2.0	2.3	0.3	1.4	1.7	2.3	2.1	2.3	1.1	1.7	0.5	1.1	2.7	2.8
March.... 5	1.8	2.2	0.3	1.4	1.4	2.2	2.0	2.2	1.0	1.5	0.3	1.0	2.7	2.7
10	1.6	2.1	0.2	1.2	1.2	2.1	1.8	2.1	0.9	1.4	0.2	0.9	2.7	2.7
15	1.4	1.9	0.1	1.2	1.1	2.0	1.8	2.0	0.7	1.4	0.2	0.9	2.6	2.6
20	1.2	1.8	0.0	1.2	0.9	1.9	1.6	2.0	0.6	1.3	0.1	1.0	2.6	2.6
25	0.9	1.8	0.0	1.1	0.8	1.7	1.5	1.9	0.5	1.4	0.0	0.8	2.5	2.5
31	0.8	1.6	—0.1	1.1	0.6	1.5	1.3	1.7	0.4	1.4	—0.1	0.8	2.5	2.5
April..... 5	0.6	1.5	—0.3	0.9	0.5	1.4	1.1	1.6	0.5	1.3	—0.1	0.6	2.4	2.5
10	0.5	1.4	—0.3	1.0	0.5	1.2	0.9	1.5	0.2	1.3	—0.2	0.6	2.3	2.5
15	0.4	1.4	—0.3	0.9	0.4	1.0	0.8	1.3	0.2	1.2	—0.3	0.5	2.2	2.5
20	0.3	1.3	—0.4	0.9	0.3	0.9	0.7	1.2	0.3	1.1	—0.3	0.5	2.2	2.4
25	0.1	1.3	—0.5	0.8	0.3	0.9	0.6	1.0	0.4	1.1	—0.4	0.4	2.3	2.3
30	0.0	1.2	—0.5	0.7	0.2	0.9	0.4	0.9	0.3	1.0	—0.4	0.3	2.2	2.3
May...... 5	—0.1	1.2	—0.4	0.7	0.1	0.9	0.4	0.9	0.3	1.1	—0.5	0.3	2.2	2.2
10	—0.2	1.2	—0.5	0.6	0.1	0.9	0.3	1.1	0.3	1.0	—0.5	0.2	2.0	2.2
15	—0.2	1.2	—0.6	0.6	0.0	0.8	0.3	1.0	0.2	1.0	—0.5	0.2	2.0	2.2
20	—0.3	1.1	—0.6	0.5	—0.1	0.8	0.2	1.0	0.1	1.0	—0.6	0.2	1.9	2.1
25	—0.3	1.0	—0.6	0.5	—0.1	0.7	0.2	0.8	0.0	1.0	—0.6	0.1	2.0	2.1
31	—0.3	0.6	—0.5	0.4	—0.1	0.7	0.2	0.8	0.1	0.9	—0.6	0.0	2.2	2.0
June...... 5	—0.2	0.5	0.4	0.4	0.0	0.6	0.2	0.7	0.2	0.7	—0.7	0.0	2.4	2.0
10	—0.1	0.4	0.9	0.4	0.2	0.6	0.1	0.7	0.4	0.7	—0.7	0.0	2.4	2.1
15	1.7	0.4	0.7	0.5	0.0	0.5	0.2	0.7	0.8	0.7	—0.7	0.0	2.4	2.3
20	1.7	1.0	0.6	0.9	—0.1	0.6	0.4	0.6	1.0	0.8	—0.6	—0.2	2.3	2.2
25	2.5	1.6	1.1	1.0	0.2	0.6	1.3	0.6	1.0	1.0	—0.3	—0.2	2.3	2.2
30	2.4	2.3	1.5	1.0	0.7	0.5	2.0	0.7	1.2	1.3	0.6	—0.2	2.3	2.1
July...... 5	2.2	2.5	1.7	1.1	1.0	0.7	2.2	1.3	1.8	1.2	0.9	—0.2	2.8	2.1
10	2.1	2.5	2.2	1.5	1.4	0.8	2.9	1.5	2.1	1.2	1.1	0.4	3.5	2.1
15	2.3	2.4	2.7	1.7	2.1	1.0	3.1	1.8	3.2	1.4	1.4	0.8	4.0	2.6
20	2.8	2.3	3.4	2.2	3.4	1.1	3.6	2.4	3.2	1.6	2.5	1.0	4.6	3.5
25	3.2	2.4	4.9	2.9	3.8	2.3	3.9	2.8	7.3	2.4	3.8	1.4	5.4	3.9
31	3.7	3.0	6.3	4.5	5.6	3.1	5.6	3.4	4.7	2.8	5.2	2.6	5.6	4.9
August... 5	4.0	3.3	6.9	5.9	5.9	4.6	6.2	5.0	4.9	3.6	5.6	4.1	6.4	5.1
10	6.1	3.6	7.4	6.5	7.2	5.5	7.2	5.6	5.4	4.0	6.3	4.9	7.1	5.9
15	6.7	5.2	8.5	6.9	7.7	6.9	7.1	6.5	5.8	4.7	7.2	5.4	7.7	6.5
20	7.0	5.6	8.6	7.3	8.0	6.9	7.8	6.5	6.4	4.6	7.5	6.0	8.2	6.9
25	7.3	5.9	8.7	7.5	7.8	6.8	7.6	6.7	6.1	5.3	8.1	6.3	8.4	7.0
31	7.6	6.2	8.7	7.6	8.2	6.9	8.1	6.6	6.2	5.3	7.6	6.6	8.1	7.1
September 5	7.6	6.3	9.0	7.7	8.2	7.0	8.5	6.8	6.3	5.2	8.1	6.5	7.9	7.1
10	7.4	6.3	8.8	8.0	8.3	7.2	8.6	7.1	6.1	5.3	8.5	6.8	8.2	7.0
15	7.3	6.3	8.7	8.2	8.0	7.4	8.4	7.4	6.0	5.2	8.9	7.2	8.6	7.2
20	7.2	6.2	8.4	8.3	7.7	7.8	8.3	7.7	6.0	5.2	8.9	7.6	8.3	7.7
25	6.9	6.2	8.4	8.4	7.9	7.7	8.1	8.1	6.3	5.1	9.0	7.9	7.9	8.0
30	6.5	6.2	8.2	8.4	7.9	7.6	7.7	8.1	6.1	5.3	9.1	8.2	7.7	8.1
October .. 5	6.4	6.1	7.9	8.7	7.4	7.6	7.2	7.9	5.6	5.2	8.9	8.4	7.3	7.9
10	6.1	5.8	7.6	8.5	7.1	7.5	6.8	7.6	5.2	5.0	8.5	8.7	7.0	7.5
15	5.8	5.6	7.2	8.3	6.9	7.4	6.5	7.7	4.9	4.9	7.9	8.4	6.7	7.6
20	5.4	5.3	6.6	8.0	6.7	7.8	5.9	7.4	4.6	4.6	7.6	8.1	6.4	7.4
25	5.0	5.8	6.2	7.7	6.3	7.6	5.4	7.1	4.5	4.4	7.4	7.9	6.0	7.3
31	4.5	5.3	5.6	7.0	5.8	6.9	4.9	6.0	4.0	4.2	6.8	7.7	5.5	6.6
November 5	4.1	4.8	5.2	6.4	5.5	6.2	4.6	5.3	3.7	3.9	6.3	7.5	5.2	5.9
10	3.8	4.6	4.9	5.6	5.0	5.6	4.4	4.9	3.6	3.6	5.9	7.4	4.9	5.4
15	3.5	4.4	4.6	5.3	4.6	5.2	4.2	4.5	3.4	3.7	5.5	6.9	4.6	5.0
20	3.3	4.3	4.3	4.7	4.4	4.7	4.1	4.3	3.2	3.7	5.2	6.2	4.4	4.7
25	3.1	4.1	4.2	4.5	4.2	4.4	3.9	4.1	2.9	3.5	4.9	5.5	4.3	4.5
30	3.0	4.0	4.0	4.3	3.8	4.1	3.5	3.8	2.7	3.1	4.7	5.5	4.1	4.3
December 5	2.8	3.8	3.7	4.2	3.6	3.9	3.4	3.6	2.5	2.9	4.5	4.9	4.0	4.4
10	2.7	3.4	3.6	4.0	3.6	3.7	3.2	3.4	2.4	2.7	4.4	4.7	3.8	4.0
15	2.5	3.6	3.4	3.8	3.4	3.6	3.0	3.2	2.2	2.6	4.2	4.5	3.7	3.8
20	2.4	3.5	3.3	3.6	3.2	3.5	2.9	3.1	2.1	2.5	4.1	4.4	3.6	3.7
25	2.3	3.2	3.2	3.5	3.1	3.3	2.8	2.9	2.0	2.4	3.9	4.2	3.5	3.5
31	2.1	2.9	3.0	3.3	2.9	3.2	2.7	2.8	2.0	2.3	3.8	4.0	3.4	3.5

TABLE VI [*continued*].

Assuân and Cairo gauge readings from 1873 to 1892.

YEARS	1880		1881		1882		1883		1884		1885		1886	
DATES	Assuân	Cairo	Assuân	Cairo	Assuân	Cairo	Assuân	Cairo	Assuân	Cairo	Assuân	Cairo	Assuân	Cairo
January .. 5	3.3	3.4	2.5	2.6	2.4	2.8	2.5	2.8	2.7	2.8	2.5	2.7	2.1	2.8
10	3.2	3.3	2.3	2.5	2.4	2.6	2.4	2.6	2.7	2.7	2.5	2.6	2.0	2.7
15	3.1	3.2	2.2	2.4	2.2	2.6	2.3	2.6	2.6	2.6	2.4	2.6	1.9	2.7
20	3.2	3.1	2.1	2.3	2.2	2.4	2.2	2.7	2.4	2.6	2.3	2.5	1.7	2.6
25	3.0	3.0	2.0	2.2	2.0	2.4	2.1	2.4	2.4	2.4	2.2	2.4	1.5	2.8
31	2.9	3.0	1.8	2.1	2.0	2.3	2.1	2.2	2.3	2.4	2.1	2.4	1.3	2.4
February. 5	2.9	2.9	1.8	2.0	1.8	2.3	2.0	2 1	2.3	2.5	2.0	2.5	1.2	2.3
10	2.8	2.9	1.7	1.9	1.7	2.1	1.9	2.1	2.2	2.4	1.9	2.5	1.1	2.3
15	2.8	2.9	1.5	1 8	1.6	2.0	1.8	2.0	2.1	2.3	1.8	2.5	0.9	2.5
20	2.7	2.8	1.4	1.7	1.4	1.9	1.7	1.9	2.1	2.3	1.6	2.3	0.8	2.4
25	2.6	2.7	1.2	1.6	1.2	1.8	1.7	1.8	2.0	2.3	1.4	2 3	0.8	2.2
28	2.6	2.7	1.2	1.6	1.1	1.9	1.7	1.8	2.0	2.2	1.3	2.2	0.7	2.2
March.... 5	2.5	2.6	1.1	1.5	0.9	1.8	1.6	2.8	1 9	2.2	1.1	2.1	0.6	2.0
10	2.3	2.5	1.1	1.7	0.8	1.6	1.5	1.7	1.9	2.2	1.0	1.9	0.5	2.0
15	2.3	2.5	1.0	1.6	0.7	1.5	1.5	1.7	1.8	2.1	0.8	1.8	0.5	2.1
20	2.1	2.4	0.9	1.6	0.6	1.4	1.3	1.7	1.7	2.2	0.7	1.8	0.4	2.1
25	2.0	2.3	0.7	1.5	0.5	1.2	1.3	1.6	1.5	2.0	0.6	1.6	0.4	1.9
31	1.8	2.2	0.6	1.3	0.4	1.2	1.1	1.7	1.4	1.9	0.5	1.6	0.3	1.7
April 5	1.7	2.0	0.5	1.2	0.3	1.1	0.9	1.5	1.2	1.8	0.4	1.4	0.3	1.7
10	1.6	1.8	0.4	1.1	0.2	1.0	0.8	1.4	1.1	1.7	0.3	1.4	0.2	1.8
15	1.5	1.8	0.4	1.0	—0.1	0.9	0.7	1.3	1.0	1.6	0.2	1.4	0.1	1.7
20	1.5	1.7	0.3	0.9	—0.3	0.8	0.5	1.2	0.9	1.6	0.1	1.3	0.2	1.4
25	1.4	1.6	0.2	0 9	—0.3	0.7	0.4	1.0	0.9	1.5	0.0	1.4	0.2	1.3
30	1.3	1.5	0.2	0.8	—0.1	0.7	0.2	0.8	0.9	1.5	0.0	1.3	0.1	1.2
May 5	1.2	1.4	0 2	0.7	—0.1	0.6	0.2	0.7	0.8	1.5	—0.1	1.4	0.1	1.2
10	1.1	1.3	0.0	0.7	—0.2	0.5	0.1	0.6	0.6	1.4	—0.1	1.4	0.1	1.3
15	1.1	1.3	0.0	0.7	—0.2	0.5	0.1	0.6	0.6	1.4	—0.2	1.2	0.2	1.2
20	1.1	1.6	0.1	0.6	—0.3	0.5	0.2	0.5	0.5	1.4	—0.2	1.2	0.3	1.2
25	1.1	1.5	0.2	0.5	—0.3	0.4	0.1	0.5	0.4	1.4	—0.3	1.1	0.1	1.2
31	0.9	1.4	0.2	0.5	—0.3	0.3	0.1	0.5	0.6	1.3	-0.4	1.1	0.0	1.3
June 5	0.9	1.3	0.2	0.6	—0.4	0.3	0.1	0.4	0.6	1.3	—0.4	1.1	0.0	1.2
10	0.9	1.2	0.1	0.6	—0.4	0.3	0.1	0.4	0 6	1.3	—0.4	1.1	0.1	1.2
15	1.0	1.1	0.1	0.5	—0.4	0.2	0.2	0.4	0.6	1.2	—0.4	1.1	0.4	1.2
20	1.3	1.2	0.3	0.5	—0.5	0.2	0.1	0.3	0.6	1.2	—0.4	1.0	0.4	1.2
25	1.4	1.2	0.6	0.5	—0.4	0.2	0.4	0.3	0.5	1.2	—0.2	1.1	0.6	1.2
30	1.4	1.4	0.8	0.6	+0.4	0.1	0.7	0 3	1.0	1.2	—0.9	1.1	0.8	1.3
July 5	1.7	1.4	0.9	0.7	0 7	0.1	1 5	0 5	1.4	1.1	1.8	1.1	1.2	1.2
10	2.9	1.5	1.2	0.9	0.9	0.4	2.0	0.8	1.7	1.5	2.2	1.4	1.6	1.3
15	3.8	1.8	1.8	1.0	0.9	0.6	2.4	1.4	1.9	1.5	2.9	1.7	1.7	1.4
20	4.4	2.8	2.7	1.3	1.6	0.7	3.3	1.7	2.0	1.7	3.5	1.9	2.3	1.6
25	5.4	3.5	2.9	1.8	2.8	0.7	4.0	2.0	2.6	1.8	4.7	2.4	2.7	1.7
31	5.8	4.7	3.8	2.3	3.4	1.4	6.0	3.2	3.5	2.0	6.4	3.8	4.4	2.1
August ... 5	6.2	5.1	5.0	2.8	4.5	2.5	7.0	5.4	4.2	2.4	7.5	5.6	4.7	3.0
10	7.5	2.0	4.8	4.0	5.4	3.3	6.9	6.2	6.5	3.3	7.3	6.4	5.8	3.7
15	7.2	6.6	6.5	4.0	5.7	4.3	7.1	6.0	6.5	5.6	7.2	6.3	7.5	4.9
20	7.2	6.4	6.7	4.8	7.0	4.8	7.5	6.0	6.2	5.6	7.2	6.1	7.3	6.0
25	6.8	6.1	7.3	5.7	7.6	5.7	8.0	6.2	6.3	5.3	7.8	6.0	7.3	6.1
31	7.5	5.9	8.0	6.0	7.6	6.7	7.8	6.5	7.6	5.4	7.9	6.3	7.2	6.1
September 5	7.7	6.2	8.0	6.5	7.4	6.4	8.0	6.5	7.6	6.1	7.9	6.3	7.3	6.0
10	7.5	6.2	8.0	6.7	7.1	6.3	8.2	6.6	7.3	6.0	8.0	6.5	7.9	6.0
15	7.3	6.2	8.0	6.7	7.4	6.1	8.0	6.8	7.0	5.9	7.6	6.6	7.9	6.3
20	7.2	6.2	8.1	6.7	7.4	6.2	8.0	7.0	6.7	5.8	7.1	6.7	7.8	6.4
25	7.2	6.1	7.9	6.9	7.5	6.2	7.6	7.2	6.7	5.6	6.8	6.8	7.8	6.5
30	7.6	6.1	7.4	7.0	6.9	6.3	7.5	7.3	6.6	5 7	6.5	6.7	7.3	6.9
October... 5	7.0	6.5	7.1	7.0	6.3	6.1	7.0	7.2	6.2	5.7	6.5	6.5	6 7	6.8
10	6.6	6.2	6.6	6.9	6.0	5.8	6.5	7.8	6.1	5.6	6.4	6 4	6.1	7.7
15	6.0	5.9	6.3	7.7	5.6	5.6	6.0	7.5	6.0	5.5	6.0	7.1	5.8	6.6
20	5.5	6.4	5.9	7.4	5.4	6.0	5.7	7.1	6.0	5.6	5.5	6.9	5.4	6.4
25	5.0	6.1	5.5	6.8	5.3	5.9	5.6	6.8	6.1	7.0	5.0	6.3	5.1	6.6
31	4.6	5.9	5.1	6.0	5.0	6.4	5.2	6.1	5.7	6.4	4.6	5.4	4.7	5.6
November 5	4.2	5.4	4.8	5.5	5.0	5.7	4.8	5.4	5.2	6.0	4.2	4.7	4.3	5.0
10	3.9	4.8	4.5	4.9	5.0	5.4	4.5	4.9	4.7	5.1	3.9	4.2	3.9	4.3
15	3.7	4.0	4.2	4.5	4.7	5.0	4.2	4.5	4.4	5.0	3 8	3.8	3.7	3.9
20	3.5	3.8	3.8	4.2	4.4	4.8	4.0	4.2	4.2	4.5	3.4	3.6	3.5	3.6
25	3.3	3.6	3.6	3.9	4.2	4.4	4.8	4.0	3.9	4.3	3.1	3.3	3.3	3.4
30	3.2	3.4	3.5	3.7	3.9	4.2	3.6	3.8	3.7	4.0	3.0	3.4	3.3	3.3
December 5	3.1	3.3	3.2	3.6	3.6	3.9	3.5	3.6	3.5	3.7	2.9	3.2	3.4	3.2
10	3.0	3.1	3.1	3.4	3.3	3.6	3.4	3.5	3.3	3.5	2.8	3.2	3.3	3.3
15	2.9	3.1	2.9	3.2	3.0	3.4	3.3	3.3	3.1	3.3	2.6	3.1	3.1	3.3
20	2.8	3.0	2.8	3.1	2.9	3.1	3.1	3.2	2.9	3 2	2.5	3.0	3.0	3.2
25	2.7	2.9	2.7	3.0	2.7	3.0	2.9	3.1	2.8	3.0	2.4	2.9	2.7	3.0
31	2.6	2.8	2.5	2.8	2.6	2.8	2.9	2.9	2.7	2.8	2.2	2.9	2.5	2.8

TABLE VI [*continued*].

Assuân and Cairo gauge readings from 1873 to 1892.

YEARS	1887		1888		1889		1890		1891		1892		MEAN OF 20 YEARS FROM 1873 to 1892	
DATES	Assuân	Cairo	Assuân	Cairo	Assuân	Cairo	Assuân	Cairo	Assuân	Cairo	Assuân	Cairo	Assuân	Cairo
January .. 5	2.5	2.7	2.8	2.8	1.5	1.8	2.2	2.2	2.8	2.8	2.6	2.7	2.6	2.8
10	2.4	2.6	2.7	2.7	1.4	1.8	2.1	2.1	2.7	2.7	2.5	2.6	2.5	2.7
15	2.3	2.5	2.6	2.6	1.3	1.7	2.0	2.1	2.6	2.5	2.4	2.4	2.3	2.6
20	2.2	2.4	2.4	2.5	1.1	1.7	1.9	1.9	2.5	2.4	2.3	2.3	2.2	2.5
25	2.1	2.3	2.3	2.4	0.9	1.6	1.8	1.9	2.4	2.3	2.2	2.2	2.1	2.4
31	2.0	2.3	2.1	2.2	0.7	1.5	1.6	1.8	2.2	2.2	2.0	2.1	2.0	2.3
February. 5	1.8	2.2	1.9	2.1	0.6	1.4	1.4	1.8	2.4	2.2	1.9	2.0	1.9	2.2
10	1.7	2.1	1.7	2.0	0.5	1.4	1.2	1.7	1.9	2.2	1.7	2.1	1.7	2.2
15	1.5	2.0	1.5	1.8	0.4	1.4	1.0	1.6	1.5	2.1	1.6	2.0	1.6	2.1
20	1.4	2.2	1.3	1.8	0.3	1.3	0.8	1.5	1.4	2.0	1.4	2.0	1.5	2.0
25	1.2	1.8	1.3	1.7	0.2	1.3	0.8	1.6	1.2	1.9	1.2	1.9	1.4	1.9
28	1.1	1.8	1.2	1.7	0.2	1.2	0.6	1.5	1.1	1.8	1.0	1.9	1.3	1.9
March.... 5	1.0	2.0	0.1	1.7	0.1	1.2	0.5	1.5	0.9	1.8	0.9	1.8	1.2	1.8
10	0.9	1.9	0.9	1.6	0.0	1.2	0.4	1.4	0.8	1.7	0.8	1.7	1.1	1.8
15	0.8	1.8	0.8	1.5	—0.1	1.2	0.3	1.4	0.6	1.8	0.6	1.7	1.0	1.7
20	0.7	1.7	0.8	1.4	0.0	1.2	0.2	1.4	0.5	1.6	0.5	1.7	0.9	1.6
25	0.5	1.5	0.7	1.4	-0.1	1.2	0.2	1.4	0.4	1.6	0.4	1.6	0.8	1.6
31	0.3	1.3	0.5	1.4	—0.2	1.2	0.0	1.2	0.3	1.6	0.3	1.8	0.6	1.5
April..... 5	0.2	1.2	0.4	1.3	—0.3	1.1	-0.1	1.3	0.3	1.8	0.2	1.8	0.5	1.5
10	0.2	1.2	0.4	1.3	—0.3	1.1	—0.2	1.3	0.2	1.8	0.0	1.8	0.4	1.4
15	0.1	1.0	0.4	1.3	—0.3	1.1	—0.3	1.3	0.1	1.8	—0.1	1.8	0.4	1.3
20	0.1	1.2	0.3	1.3	—0.4	1.1	—0.3	1.2	0.1	1.8	—0.1	1.7	0.3	1.3
25	0.1	1.2	0.3	1.2	—0.4	1.1	—0.3	1.2	—0.1	1.7	—0.2	1.7	0.3	1.2
30	0.0	**0.8**	0.2	1.3	—0.5	1.1	—0.4	1.2	—0.2	1.7	—0.3	1.8	0.2	1.2
May...... 5	0.0	1.1	0.1	1.2	—0.4	1.1	—0.5	1.2	—0.2	1.7	—0.4	1.7	0.2	1.1
10	0.1	1.1	0.1	1.2	—0.5	1.1	—0.5	1.2	—0.1	1.7	—0.4	1.7	0.1	1.1
15	0.3	1.0	0.1	1.2	—0.6	1.1	—0.5	1.2	**—0.2**	1.7	—0.4	1.7	0.1	1.1
20	0.2	1.1	0.2	1.2	—0.6	1.1	-0.5	1.2	—0.2	**1.6**	—0.5	1.7	0.0	1.1
25	0.1	1.1	0.1	1.2	—0.5	1.0	**—0.6**	1.2	0.0	1.6	—0.4	1.5	**0.0**	1.0
31	0.3	1.2	0.0	1.2	—0.6	1.0	—0.6	1.0	0.0	1.6	—0.6	1.4	0.1	1.0
June..... 5	0.6	1.2	**—0.1**	1.1	**—0.6**	1.0	—0.5	1.0	0.1	1.7	**—0.6**	1.4	0.1	0.9
10	0.4	1.2	0.0	1.1	—0.4	1.0	-0.4	1.0	0.6	1.7	—0.5	1.4	0.2	0.9
15	0.4	1.1	0.1	**1.0**	—0.5	0.9	—0.3	**0.9**	1.5	1.7	—0.5	1.3	0.4	**0.9**
20	0.9	1.1	0.2	1.0	—0.5	1.0	—0.1	1.0	1.7	1.7	—0.4	**1.2**	0.5	0.9
25	1.3	1.1	0.4	1.1	—0.4	1.0	0.3	1.0	1.8	1.8	—0.2	1.3	0.7	1.0
30	1.4	1.2	0.6	1.2	+0.1	0.9	0.5	1.1	1.7	2.0	—0.2	1.3	1.1	1.1
July...... 5	1.8	1.5	0.8	1.2	0.5	**0.9**	0.8	1.3	1.7	2.2	0.6	1.4	1.4	1.1
10	2.1	1.5	0.9	1.2	0.9	1.0	1.7	1.7	1.9	2.2	1.0	1.6	1.8	1.3
15	2.8	1.7	1.2	1.3	1.2	1.2	2.0	1.8	2.1	2.2	1.6	1.7	2.3	1.5
20	3.9	1.8	1.4	1.3	1.8	1.2	2.6	1.9	2.2	2.2	2.4	2.1	2.9	1.8
25	4.6	2.9	3.1	1.3	3.1	1.4	3.0	2.0	2.8	2.3	3.8	2.2	3.7	2.2
31	5.9	3.9	3.4	1.6	5.8	1.8	5.7	2.3	4.6	2.3	5.4	2.7	5.0	2.9
August... 5	6.9	5.2	4.9	2.1	5.7	4.2	6.3	4.4	5.4	3.2	6.3	3.9	5.7	4.1
10	8.1	6.3	6.1	3.5	6.5	4.8	7.0	5.6	6.8	4.2	6.8	5.3	6.6	4.9
15	8.4	6.9	6.3	4.9	6.8	5.3	7.8	6.1	7.0	5.7	6.7	5.8	7.0	5.7
20	8.5	7.0	6.2	5.3	7.4	5.5	8.0	6.3	7.4	5.8	7.4	5.4	7.3	5.9
25	8.4	7.2	**7.0**	5.7	7.7	6.0	8.4	6.5	7.7	5.9	8.3	5.8	7.6	6.2
31	**8.8**	7.1	6.8	5.7	**8.3**	6.2	**8.6**	6.8	7.6	6.2	8.3	6.6	7.8	6.4
September 5	8.7	7.4	6.9	5.7	8.3	6.7	8.5	7.0	7.9	6.3	8.6	6.9	**7.9**	6.5
10	8.7	7.7	7.0	5.8	7.9	6.8	8.2	7.2	7.8	6.4	8.8	7.1	7.9	6.7
15	8.6	8.1	6.8	**5.8**	8.0	6.8	8.2	7.3	**7.9**	5.8	8.8	7.5	7.9	6.8
20	8.4	8.3	6.4	5.7	7.8	7.0	8.0	7.5	7.9	6.4	**8.9**	7.9	7.7	6.9
25	8.1	**8.4**	6.4	5.6	7.7	7.0	7.8	7.5	7.8	6.5	8.6	8.1	7.6	7.0
30	7.7	8.3	6.0	5.5	7.3	7.1	7.6	7.5	7.6	**6.6**	8.4	8.3	7.4	**7.1**
October .. 5	7.1	8.1	5.6	5.1	6.9	7.1	7.4	7.4	7.1	6.4	8.2	**8.4**	7.0	6.9
10	6.8	8.0	5.1	4.8	6.7	**7.1**	7.2	7.4	6.8	6.3	7.8	8.3	6.7	6.9
15	6.4	7.7	4.7	4.4	6.5	7.1	7.2	7.4	6.5	6.3	7.4	8.1	6.3	6.8
20	6.0	7.3	4.4	4.1	6.0	6.9	6.8	7.4	6.7	7.0	7.2	7.9	6.0	6.8
25	5.6	6.8	4.0	3.8	5.4	6.4	6.5	**7.6**	6.3	**7.2**	6.8	7.9	5.7	6.7
31	5.1	5.9	3.5	3.7	4.8	6.2	6.3	7.1	5.8	6.9	6.3	7.8	5.2	6.2
November 5	4.8	5.2	3.2	3.7	4.4	5.3	5.8	6.7	5.5	6.3	5.7	7.2	4.8	5.6
10	4.5	4.7	2.9	3.1	4.1	4.5	5.3	6.1	5.3	5.6	5.3	6.4	4.5	5.1
15	4.3	4.3	2.7	2.8	3.7	4.0	4.9	5.4	5.1	5.0	5.0	5.6	4.2	4.7
20	4.0	4.0	2.5	2.6	3.5	3.6	4.6	4.8	4.8	4.8	4.6	4.8	4.0	4.3
25	3.8	3.8	2.4	2.4	3.3	3.4	4.2	4.3	4.4	4.4	4.4	4.4	3.8	4.0
30	3.6	3.7	2.2	2.3	3.0	3.1	4.0	4.0	4.1	4.2	4.1	4.2	3.6	3.8
December 5	3.5	3.5	2.2	2.2	2.8	2.9	3.8	3.8	3.7	3.8	3.9	3.9	3.4	3.6
10	3.3	3.3	2.1	2.2	2.8	2.7	3.7	3.6	3.5	3.6	3.8	3.7	3.2	3.4
15	3.2	3.1	1.9	2.2	2.6	2.6	3.5	3.4	3.3	3.3	3.6	3.5	3.1	3.3
20	3.1	3.0	1.9	2.0	2.5	2.5	3.3	3.3	3.2	3.2	3.5	3.3	3.0	3.2
25	3.1	2.9	1.8	1.9	2.4	2.4	3.1	3.2	3.0	3.1	3.4	3.2	2.9	3.0
31	2.9	2.9	1.6	1.9	2.3	2.3	2.9	3.0	2.8	2.9	3.3	3.1	2.7	2.9

TABLE VII.

Discharge table of the Upper Egypt canals.

A low Nile flood is 6.4 metres
A mean Nile flood is 7.5 »
A high Nile flood is 8.3 »
} at Assuân.

The discharges of the Upper Egypt canals corresponding to the Assuân gauges are appoximately as follows : —

Assuân	6.0	1300	
	.1	1370	
	.2	1440	
	.3	1510	
	.4	1580	— Low Nile flood.
	.5	1650	
	.6	1720	
	.7	1790	
	.8	1860	
	.9	1930	
	7.0	2000	
	.1	2070	
	.2	2140	
	.3	2210	
	.4	2280	
	.5	2350	— Mean Nile flood.
	.6	2420	
	.7	2490	
	.8	2560	
	.9	2630	
	8.0	2700	
	.1	2770	
	.2	2840	
	.3	2910	— High Nile flood.
	.4	2980	
	.5	3050	
	.6	3120	
	.7	3190	
	.8	3260	
	.9	3330	
	9.0	3400	

TABLE VIII.

Mean low water level of the Nile.

DISTANCE FROM ASSUAN ALONG CENTRE OF FLOOD	NAME OF LOCALITY	R.L. ACCORDING TO RESERVOIR LEVELS	R.L. ACCORDING TO INSPECTORS OF IRRIGATION	DISTANCE FROM ASSUAN ALONG SUMMER CHANNEL
0	Assuàn	85.0	85.0	0
70	Gebel Silsila	79.3	79.4	72
100	Edfu	76.7	77.0	..
157	Esna	73.1	72.6	..
194	Armant	70.1	69.6	..
213	Luxor	69.0	68.5	..
272	Kena	65.3	64.8	..
320	Kasr-es-Saad	61.7	61.2	330
328	Heu	61.2	60.7	..
333	Naga Hamadi	61.0	60.5	..
365	Abu Shusha	58.6	58.1	..
373	Balyana	58.3	57.8	..
390	Girga	56.9	56.5	..
429	Sohàg	53.8	53.2	..
470	Khazindaria	49.9	49.4	489
505	Aboutig Escape	47.7	47.1	..
530	Assiout (1)	45.55	45.05	552
598	Derut Escape	39.1	38.5	..
627	Roda	36.3	35.7	..
666	Minia	32.6	32.0	..
710	Beni Mazàr	28.9	..	748
..	Beni Suèf (2)	22.1	21.8	..
800	Ashmant	20.5	20.2	842
..	Kushesha Escape	18.9	18.6	..
..	El-Ayàt	15.8	15.5	..
898	Cairo gauge	12.10	12 25	..
900	Cairo	12.00	12.1	948
923	The Barrage	11 0	11.0	973

(1) Below Ibrahimia Canal Head.

(2) The Beni Suèf gauge is unreliable in summer as it is on a branch of the river which is dammed by the villagers.

TABLE IX.

Slope of water surface in the Nile.

FROM	TO	DISTANCE IN KILOMETRES DOWN THE CENTRE LINE OF THE FLOOD	DISTANCE IN KILOMETRES DOWN THE SUMMER CHANNEL	SLOPE IN FLOOD	SLOPE IN SUMMER
Assuân	Silsila	70	72	$\frac{1}{11500}$	$\frac{1}{12600}$
Silsila	Kasr-es-Saad	250	258	$\frac{1}{14800}$	$\frac{1}{14800}$
Kasr-es-Saad	Khazindaria	150	159	$\frac{1}{12300}$	$\frac{1}{13400}$
Khazindaria	Assiout	60	63	$\frac{1}{11800}$	$\frac{1}{14500}$
Assiout	Beni Mazâr	180	196	$\frac{1}{11000}$	$\frac{1}{11800}$
Beni Mazâr	Ashmant	90	94	$\frac{1}{11000}$	$\frac{1}{11400}$
Ashmant	Cairo	100	106	$\frac{1}{11600}$	$\frac{1}{12300}$
Cairo	Barrage	23	25	$\frac{1}{10800}$	$\frac{1}{20000}$
Assuân	Cairo	900	948	$\frac{1}{12200}$	$\frac{1}{13000}$

TABLE X.

Maximum flood gauges of 1892.

KILO: FROM ASSUAN	LOCALITY	GAUGE	KILO: FROM ASSUAN	LOCALITY	GAUGE	KILO: FROM ASSUAN	LOCALITY	GAUGE
0	Assuàn	8.9	300	Kena (continued).	9.3	600	Assiout (continued)	8.2
10		8.8	10		9.2	10		8.2
20		8.7	20	Kasr-es-Saâd	9.2	20		8.2
30		8.7	30		8.8	30		8.3
40		8.6	40		8.8	40		8.3
50		8.6	50		8.9	50		8.3
60		8.5	60		8.9	60		8.3
70	Gebel Silsila	8.5	70		8.8	70	Minia	8.3
80		8.6	80		8.7	80		8.3
90		8.6	90	Girga	8.6	90		8.3
100		8.7	400		8.6	700		8.3
10		8.7	10		8.7	10	Beni-Mazar	8.3
20		8.9	20		8.8	20		8.2
30		9.0	30	Sohag	8.9	30		8.1
40		9.1	40		9.1	40		8.0
50		9.1	50		8.9	50		7.8
60	Esna	9.1	60		8.9	60		7.8
70		9.2	70	Khazindaria	8.9	70		7.7
80		9.2	80		8.8	80	Beni Suêf	7.8
90		9.3	90		8.6	90		8.0
200	Armant	9.4	500		8.5	800	Ashmant	8.2
10		9.4	10		8.5	10		8.5
20		9.3	20		8.3	20	Kushesha	8.5
30		9.3	30	Assiout	8.2	30		8.4
40		9.2	40		8.2	40		8.1
50		9.1	50		8.2	50		8.1
60		9.0	60		8.2	60		8.1
70	Kena	8.9	70		8.3	70		8.2
80		9.0	80		8.3	80		8.2
90		9.2	90		8.3	90		8.2
						900	Cairo	8.3*
						10		7.8
						20	Barrage	7.3

* This differs by 10 centimetres from the gauge on page 22 as there is this difference between the Reservoir levels and the Irrigation Department levels.

TABLE XI.

Table giving areas of cross sections of the Nile, from Assuân to Cairo.

LOCALITY	LENGTH IN KILOMETRES	MEAN AREA IN SQUARE METRES					
		BELOW ZERO	BELOW 6 METRES	BELOW 7 METRES	BELOW 8 METRES	BELOW 8.5 METRES	BELOW 9 METRES
Assuân to Ramâdi........	81	1024	4930	5808	6754	7337	7993
Ramâdi to Esna..........	76	674	4554	5461	6398	6966	7695
Esna to Kena............	115	852	4476	5336	6221	6726	7363
Kena to Sohâg...........	158	973	4718	5600	6535	7121	7873
Sohâg to Assiout.........	98	1037	5220	6305	7705	8683	9749
Assiout to Minia..........	138	899	5149	6205	7783	8845	9937
Minia to Beni-Suêf........	117	915	5035	6007	7315	8196	9140
Beni-Suêf to Koshesha....	34	665	5040	6080	7532	8379	9247
Koshesha to Cairo........	81	1031	5364	6388	7813	8648	9495
Cairo to the Barrage......	24	1402	5414	6628	8346	9258	10184
Assuân to Assiout........	528	920	4760	5680	6690	7310	8080
Assiout to Koshesha......	289	870	5080	6100	7550	8510	9520
Koshesha to Cairo........	81	1030	5360	6380	7810	8640	9490
Assuân to Cairo..........	898	910	4930	5890	7080	7830	8690

LOCALITY	LENGTH IN KILOMETRES	MEAN AREA IN SQUARE METRES					
		BELOW ZERO	FROM ZERO TO 6.0	FROM 6.0 TO 7.0	FROM 7.0 TO 8.0	FROM 8.0 TO 8.5	FROM 8.5 TO 9.0
Assuân to Ramâdi........	81	1024	3906	878	946	583	656
Ramâdi to Esna..........	76	674	3880	907	937	568	729
Esna to Kena............	115	852	3624	860	885	505	637
Kena to Sohag...........	158	973	3746	881	935	586	752
Sohag to Assiout.........	98	1037	4183	1085	1400	978	1066
Assiout to Minia..........	138	899	4250	1056	1578	1062	1092
Minia to Beni-Suêf.......	117	915	4120	972	1308	881	944
Beni-Suêf to Koshesha....	34	665	4375	1040	1452	847	868
Koshesha to Cairo........	81	1031	4333	1024	1425	835	847
Cairo to the Barrage......	24	1402	4012	1214	1717	912	926
Assuân to Assiout........	528	920	3840	910	1010	610	760
Assiout to Koshesha......	289	870	4210	1020	1450	960	1000
Koshesha to Cairo........	81	1030	4330	1020	1420	830	840
Assuân to Cairo..........	898	910	4010	960	1190	740	860

TABLE XII.

Table of the cubic contents of the trough of the Nile in millions of cubic metres.

LOCALITY	LENGTH IN KILOMETRES	CONTENTS IN MILLIONS OF CUBIC METRES.						CONTENTS IN MILLIONS OF CUBIC METRES					
		BELOW ZERO	FROM ZERO TO 6.0	FROM 6.0 TO 7.0	7.0 TO 8.0	8.0 TO 8.5	8.5 TO 9.0	BELOW ZERO	BELOW 6.0	BELOW 7.0	BELOW 8.0	BELOW 8.5	BELOW 9.0
Aswàn to Ramadi........	81	83	316	711	77	47	53	83	299	470	547	594	647
Ramadi to Esna..........	76	51	295	69	71	43	56	51	346	415	486	529	585
Esna to Kena............	115	98	417	99	102	58	73	93	514	614	715	773	847
Kena to Sohag...........	128	154	592	139	148	83	119	154	745	885	1032	1125	1244
Sohag to Assiout.........	98	102	410	106	137	96	104	102	512	618	755	851	955
Assiout to Minieh.........	138	124	586	146	218	147	151	124	710	856	1074	1220	1371
Minieh to Beni Suêf.......	117	107	482	114	153	103	110	107	589	703	856	859	1069
Beni Suêf to Kushesha....	34	23	149	35	49	29	29	23	171	207	256	285	314
Kushesha to Cairo........	81	84	351	83	115	68	69	84	434	517	633	700	769
Cairo to the Barrage......	28	34	96	29	41	22	22	34	130	159	200	222	244
Aswàn to Assiout.........	528	487	2030	484	534	327	405	487	2517	3001	3535	3862	4267
Assiout to Kushesha......	289	254	1217	295	420	278	291	254	1471	1766	2186	2461	2755
Kushesha to Cairo........	81	84	351	83	115	68	69	84	435	518	633	701	770
Aswàn to Cairo..........	898	825	3598	862	1069	673	765	825	4423	5285	6354	7027	7792

TABLE XIII.

Widths of water surface from Assuân to Cairo.

From	To	MEAN WIDTH OF WATER SURFACE					
		0	6.0	7.0	8.0	8.5	9.0
Assuân..........	Ramadi........	400	840	880	1030	1270	1400
Ramadi	Esna	340	850	890	1030	1260	1620
Esna............	Kena..........	350	820	850	940	1120	1400
Kena............	Sohag	380	870	890	1000	1300	1560
Sohag...........	Assiout........	400	1000	1170	1720	2080	2170
Assiout..........	Minieh	390	970	1180	1890	2060	2080
Minieh	Beni Suèf......	490	960	1300	1550	1800	1840
Beni Suèf........	Kushesha......	500	1000	1390	1690	1720	1730
Kushesha	Cairo..........	450	960	1100	1570	1700	1700
Cairo............	Barrage........	440	940	1460	1840	1860	1890
Assuân..........	Assiout........	370	880	940	1140	1410	1630
Assiout..........	Kushesha......	460	980	1290	1710	1860	1880
Kushesha	Cairo..........	450	960	1100	1570	1700	1700
Assuân..........	Cairo..........	430	940	1110	1470	1660	1740

Area of water surface in millions of square metres.

Assuàn..........	Assiout........	200	470	500	600	740	860
Assiout..........	Cairo..........	130	280	370	490	540	540
Assuân..........	Cairo..........	400	840	1000	1320	1490	1560

Evaporation (at 8 millimes per day) in cubic metres per second.

Assuân....	Assiout........	20	47	50	60	74	86
Assiout..........	Cairo..........	13	28	37	49	54	54
Assuân..........	Cairo..........	40	84	100	132	149	156

TABLE XIV.

Table giving dates and heights of the real minimum at the Assuân gauge.

			MINIMUM GAUGE OF THE YEAR IN METRES
1873.........	5th June..............................	—	.37 Metres.
1874.........	30th May..............................	—	.64
1875....	23rd May..............................	—	.17
1876.........	15th June..............................	+	.13
1877.........	27th May..............................	+	.10
1878.........	23rd June..............................	—	.71 Worst low supply.
1879.........	23rd May..............................	+	1.88 Best low supply.
1880.........	9th June..............................	+	.82
1881.........	14th May..............................	+	.00
1882.........	23rd June..............................	—	.55
1883.........	22nd June..............................	+	.04
1884.........	27th May..............................	+	.37
1885.........	21st June..............................	—	.44
1886.........	3rd June..............................	—	.06
1887.........	8th May..............................	—	.03
1888.........	8th June..............................	—	.08
1889.........	24th June..............................	—	.60
1890.........	8th June..............................	—	.60
1881.........	19th May..............................	—	.21
1892.........	18th June..............................	—	.64

7 Years are above and 13 years are bellow the mean low water level.

The mean of the minimums is — 0.08 metres.

TABLE XV.

Table giving the dates and the heights of the maximum flood at Assuân.

		GAUGE.	
1873.........	1st September..........................	7.66 metres.	
1874.........	6th September..........................	8.97	
1875.........	11th September..........................	8.36	
1876.........	7th September..........................	8.68	
1877.........	20th August............................	6.40	
1878.........	1st October............................	9.15	
1879.........	13th September..........................	8.59	
1880.........	4th September..........................	7.82	
1881.........	4th September..........................	8.14	
1882.........	28th August............................	8.00	— 22nd September 7.60
1883.........	17th September..........................	8.18	
1884.........	1st September..........................	7.73	
1885.........	28th August............................	8.05	— 10th September 8.00
1886.........	22nd September..........................	8.04	
1887.........	1st September..........................	8.81	
1888.........	24th August............................	7.08	
1889.........	2nd September..........................	8.36	
1890.........	2nd September..........................	8.72	
1891.........	4th September..........................	7.84	— 27th September 7.84
1892.........	20th September..........................	8.88	

The mean of the maximums is....................... 8.17

A mean high flood is .... 7.90 metres.

TABLE XVI.

Table showing the amount of water which reaches the Sea in an average year.

From Table II, the mean discharge at Cairo = 2610 cubic metres per second.

The Delta Canals absorb for the irrigation of Lower Egypt: —

January	300 cubic metres per second.
February	300
March	300
April	300
May	350
June	400
July	500
August	1000
September	1200
October	1200
November	500
December	300
Mean for the year	550 cubic metres per second.

∴ The mean discharge to the Sea = 2610 — 550 = 2060 cubic metres per second.

Or 65,000,000,000 cubic metres per annum.

As the average rainfall in the Nile basin has been found to the 2,633,000,000,000, the water which reaches the Sea= $\frac{1}{40}$th of the rainfall.

TABLE XVII.

Table giving the tons of solid matter carried of the sea in an average year.

	DISCHARGE OF THE NILE AT CAIRO M^3 PER SECOND	DISCHARGE OF THE DELTA CANALS M^3 PER SECOND	DISCHARGE ENTERING THE SEA M^3 PER SECOND
June	410	410	0
July	1010	500	510
August	5280	1000	4280
September	7200	1200	6000
October	6860	1200	5660
November	3740	500	3240
December	2260	300	1960
January	1590	300	1290
February	1120	300	820
March	800	300	500
April	550	300	250
May	430	350	80

Solids carried in suspension.

				M^3 PER SECOND
June	0	$\times \frac{6.9}{100.000}$	=	0.000
July	510	$\times \frac{17.8}{100.000}$	=	0.098
August	4280	$\times \frac{149.2}{100.000}$	=	6.386
September	6000	$\times \frac{54.3}{100.000}$	=	3.258
October	5660	$\times \frac{37.8}{100.000}$	=	2.139
November	3240	$\times \frac{34.4}{100.000}$	=	1.114
December	1960	$\times \frac{28.9}{100.000}$	=	.566
January	1290	$\times \frac{16.7}{100.000}$	=	.205
February	820	$\times \frac{12.6}{100.000}$	=	.103
March	500	$\times \frac{5.3}{100.000}$	=	.026
April	250	$\times \frac{6.6}{100.000}$	=	.016
May	80	$\times \frac{4.8}{100.000}$	=	.004
			MEAN.....	1.1596

Total quantity of solids carried to the sea in one year $365 \times 1.1596 \times 86,400 = 36,569,000$ cubic metres or say 36,600,000 tons.

TABLE XVIII.

Cairo gauges corresponding to Assuân gauges if Basin irrigation is changed into perennial irrigation.

1874

DATE AT ASSUAN		GAUGES AT ASSUAN	DISCHARGES AT ASSUAN	WATER CONSUMPTION ASSUAN TO CAIRO	TROUGH OF NILE ASSUAN TO CAIRO	DISCHARGE AT CAIRO	GAUGES AT CAIRO	DATE AT CAIRO
August......	5	6.9	7600	—1020	—1000	5580	5.8	10th August.
»	10	7.4	8600	do	do	6580	6.4	15th »
»	15	8.5	11500	do	do	9480	7.8	20th »
»	20	8.6	11800	do	do	9780	7.9	25th »
»	25	8.7	12100	do	do	10080	8.1	31st »
»	31	8.7	12100	do	do	10080	8.2	5th September.
September...	5	9.0	12800	do	do	10780	8.3	10th »
»	10	8.8	11800	do	0	10780	8.4	15th »
»	15	8.7	11500	do	+500	10980	8.5	20th »
»	20	8.4	10600	do	do	10080	8.2	25th »
»	25	8.4	10600	do	do	10080	8.2	30th »
»	30	8.2	10050	do	do	9430	7.9	5th October.
October......	5	7.9	9300	do	do	8780	7.6	10th »
»	10	7.6	8600	do	+700	8280	7.4	15th »
»	15	7.2	7800	do	do	7480	7.0	20th »
»	20	6.6	6600	do	do	6280	6.3	25th »
»	25	6.2	6000	do	do	5680	5.9	31st »
»	31	5.6	5100	do	do	4780	5.3	5th November.
November...	5	5.2	4500	do	do	4180	4.3	10th »

TABLE XVIII [continued].

Cairo gauges corresponding to Assuân gauges if Basin irrigation is changed into perennial irrigation.

1878

DATE AT ASSUAN	GAUGES AT ASSUAN	DISCHARGES AT ASSUAN	WATER CONSUMPTION ASSUAN TO CAIRO	TROUGH OF NILE ASSUAN TO CAIRO	DISCHARGES AT CAIRO	GAUGES AT CAIRO	DATE AT CAIRO
August....... 5	5.6	5400	—1020	—800	3580	4.4	10th August.
» 10	5.3	6500	do	do	4680	5.2	15th »
» 15	7.2	8200	do	do	6380	6.3	20th »
» 20	7.5	8600	do	do	6780	6.5	25th »
» 25	8.1	10000	do	do	8180	7.3	31st »
» 31	7.6	8800	do	+800	8580	7.5	5th September.
September.... 5	8.1	10300	do	—600	8680	7.5	10th »
» 10	8.5	11500	do	do	9880	8.0	15th »
» 15	8.9	12800	do	do	11180	8.5	20th »
» 20	8.9	12500	do	do	10880	8.4	25th »
» 25	9.0	12800	do	do	11180	8.5	30th »
» 30	9.1	13200	do	do	11580	8.6	5th October.
October...... 5	8.9	12100	do	+400	11480	8.6	10th »
» 10	8.5	10900	do	+800	10680	8.4	15th »
» 15	7.9	9300	do	do	9080	8.0	20th »
» 20	7.6	8600	do	do	8380	7.4	25th »
» 25	7.4	8200	do	do	7980	7.2	31st »
» 31	6.8	7000	do	do	6780	6.6	5th November.
November.... 5	6.3	6200	do	do	5980	6.1	10th »

TABLE XVIII [continued].

Cairo gauges corresponding to Assuân gauges if Basin irrigation is changed into perennial irrigation.

1892

DATE AT ASSUAN		GAUGES AT ASSUAN	DISCHARGES AT ASSUAN	WATER CONSUMPTION ASSUAN TO CAIRO	TROUGH OF NILE ASSUAN TO CAIRO	DISCHARGES AT CAIRO	GAUGES AT CAIRO	DATE AT CAIRO
August......	5	6.3	6450	—1020	—800	4630	5.1	10th August.
»	10	6.8	7400	do	do	5580	5.8	15th »
»	15	6.7	7000	do	do	5180	6.2	20th »
»	20	7.4	8600	do	do	6780	6.5	25th »
»	25	8.3	10900	do	do	9080	7.7	31st »
»	31	8.8	10900	do	do	9080	7.7	5th September.
September...	5	8.6	11800	do	do	9980	8.0	10th »
»	10	8.8	12500	do	do	10680	8.3	15th »
»	15	8.8	12500	do	do	10680	8.3	20th »
»	20	8.9	12800	do	do	10980	8.4	25th »
»	25	8.7	11500	do	+400	10880	8.4	30th »
»	30	8.4	10600	do	+800	10380	8.3	5th October.
October......	5	8.2	10500	do	do	9830	8.1	10th »
»	10	7.8	9050	do	do	8830	7.7	15th »
»	15	7.4	8200	do	do	7980	7.2	20th »
»	20	7.2	7800	do	do	7580	7.0	25th »
»	25	6.8	7000	do	do	6780	6.6	31st »
»	31	6.3	6150	do	do	5930	6.1	5th November.
November...	5	5.7	5250	do	do	5030	5.6	10th »

TABLE XVIII [continued].

Cairo gauges corresponding to Assuân gauges if Basin irrigation is changed into perennial irrigation.

1877

DATE AT ASSUAN	GAUGES AT ASSUAN	DISCHARGES AT ASSUAN	WATER CONSUMPTION ASSUAN TO CAIRO	TROUGH OF NILE ASSUAN TO CAIRO	DISCHARGES AT CAIRO	GAUGES AT CAIRO	DATE AT CAIRO
August...... 5	4.8	4200	—800	—300	3100	3.9	10th August.
» 10	5.4	5100	—1020	do	3780	4.6	15th »
» 15	5.8	5700	do	do	4380	5.0	20th »
» 20	6.4	6500	do	do	5180	5.5	25th »
» 25	6.1	5800	do	do	4480	5.1	31st »
» 31	6.2	6000	do	do	4680	5.2	5th September.
September... 5	6.3	6200	do	do	4880	5.3	10th »
» 10	6.1	5800	do	+200	4980	5.5	15th »
» 15	6.1	5700	do	do	4880	5.4	20th »
» 20	6.0	5700	do	do	4880	5.4	25th »
» 25	6.3	6200	do	do	5380	5.6	30th »
» 30	6.1	5800	do	do	4980	5.4	5th October.
October...... 5	5.6	5100	do	do	4280	5.0	10th »
» 10	5.2	4500	do	do	3680	4.6	15th »
» 15	4.9	4200	—950	do	3450	4.4	20th »
» 20	4.6	3800	—900	do	3100	4.0	25th »
» 25	4.5	3600	—850	do	2950	3.9	31st »
» 31	4.0	3100	—800	do	2500	3.5	5th November.
November... 5	3.7	2800	—700	do	2300	3.3	10th »

APPENDIX IV.

Mr. F. G. M. STONEY'S REPORT

ON THE

ROPOSED REGULATING APPARATUS FOR THE RESERVOIR DAMS.

OPEN RESERVOIR BARRAGES ON THE NILE.

The writer now has the honour to respond fully to the invitation of Mr. Willcocks to prepare a report with design and estimate on the best method of controlling the waters of the proposed Barrages on the Nile.

The writer has spent much time and labour in considering the matter very fully.

He has, at the outset, been impressed with the responsibility of the task of co-operating in a work of such immense importance to Egypt.

It is impossible to overestimate the effects of these Barrages on the prosperity and wealth of the country, and to ensure their perfect operation, it is imperative to have such appliances as will ensure the effective and absolute control of the waters, at all times and under all conditions. Thus impressed, the writer has not only prepared designs and estimates for the construction and erection of the necessary Sluices, but he also suggests that his firm should work and maintain them for a term of years, thus affording the continued benefit of his experience in working and maintaining the apparatus.

In the special circumstances of the case, it is probable that those most interested in the success of the Barrages will appreciate a willingness to undertake this continuing skilled supervision and responsibility.

The writer is prompted thereto by his long experience in such matters, he having been engaged in designing, constructing and maintaining Sluices for about 25 years past in great varieties of cases some of which are more particularly referred to at the end of this document. In the present case, he understands that each Barrage and Reservoir is of extent as to require: —

70 Sluices 10 metres high by 2 metres wide, to lift 10 metres clear of Sill, under a total head of 22 metres; and also 30 Sluices 10 metres high by 2 metres wide to lift 10 metres clear of sill under a total head of 15 metres. All the Sluices are of ample strength to meet the utmost conditions, and may safely be used to discharge water under the extreme head, when the floor of the Barrage is dry on the down stream side.

Discharging any volume of water under this maximum head, is not a question of the fitness of the Sluices, but of the effect in the river bed and banks below the Sluices.

The writer regards with satisfaction the prospect of the whole structure being founded on the solid rock; the floors of the Sluiceways being securely let into, and scaled closely to the solid bottom, will have the effect of making the whole of the masonry practically monolithic in character.

The writer does not propose to intrude on this part of the subject, as he does not understand that he is asked to take any responsibility with regard to it, but that his duties would be limited to the provision of sufficient control of waterway through the dams.

Plans giving the levels of water in the Reservoirs, and the masonry proposed, were furnished to the writer by Mr. Willcocks, and based upon these he now submits: —

1. A general plan of the work.
2. An enlarged drawing giving full outline and dimensions of the grooves necessary to be made in the masonry to receive the Sluices.

F. S. are the fixed shields or aprons extending from the top of the Sluices S to the underside of the masonry coping. S are the Sluices, or doors, mounted on the writer's well known patent system of " free rollers ".

The surface exposed to the pressure is smooth and without projections of any kind; the doors are thus able to pass closely but freely within and behind the aprons or shields above alluded to.

Both are made of substantial steel plates suitably stiffened to withstand the pressure which is calculated as 350 tons on each door. Great as this land undoubtedly is, it can easily be dealt with under the writer's free roller system, for by that method the co-efficient of resistance for lifting the door is only .0016 of the load. The dead weight of the door is of course balanced.

Although its movement is rendered thus easy, the writer proposes nevertheless to give very powerful gear for opening and closing in order to ensure the advantages of slow speed movement, which is found by experience to be of great importance.

A. A. are the roller paths of receiving the free rollers; they are secured to the masonry and also to cross beams built into the masonry. Each sluice has four such beams, the bottom beam being flush with the floor: The top one is above the level of the Sluice opening. These two beams are of such length as to extend from the centre of one pier to the centre of the next, and being bolted together at their ends, they form one continuous tie.

The two intermediate beams divide the height into convenient parts and are equal in length to the thickness of the piers at that part.

Whilst the top and bottom beams couple the roller paths of one Sluice in pairs, the intermediate beams couple the neighbouring roller paths of adjacent Sluices.

This system affords perfect facility for the true erection of the work in place, because the beams and roller paths form a complete forme work capable of being put completely together at the factory before being sent out.

They are all truly planed and fitted and so can be readily re-erected in place. This must be done as soon as the floors are laid, and they then form the guides for building up the masonry correctly and in true form to receive the Sluices.

The aprons and doors are of mild steel and are so constructed as to be practically composed of beams throughout, so as to be perfectly stiff and unyielding under the heavy pressure to which they will be subject. Each vertical edge of the door is furnished with a massive roller beam, planed throughout it's length for the purpose of working truly on the free rollers, which in their turn bear on the roller beams A fixed on the masonry which have been already alluded to.

The roller beams and rollers are placed in recesses in the masonry, so contrived as to be well out of the way of the passing current, the entrances to the Sluice Ways being also designed with the same object in view.

Stop grooves are shewn in the masonry, so that any Sluice can be at any time isolated and examined. The writer suggests this provision as a matter of prudence. As a matter of fact, he has Sluices which have been at work upwards or 10 years without requiring examination or repair any kind.

It has been already remarked that the Sluice doors are balanced. Two steel wire ropes are fixed at each sides of the door, each one of them capable of sustaining the full load. Thus, if for any cause it should be desired to remove a rop, it can be easily done. These ropes are carried up to the operating deck and passed over pulleys of large diameter, and their other ends are attached to the balance weights, which are adjusted with due regard to the average immersion of the Sluices on the down stream sides. The weight of the doors is thus almost entirely eliminated and the resistance of their movement is limited to the friction on the live rollers due to the load and the friction on the axles of the pullies.

It has already been remarked that the former is only .0016 of the load: the latter is also reduced in like manner by mounting the bearings of the axles in rollers properly prepared for them. By these means, the power required to move the doors under the heaviest pressure is so little that one man can open and close the doors without effort, and of course in perfect safety to himself. From this, it results that it is only necessary to provide one set of purchase gear for every two Sluices, and it is so arranged that one man can, at will, regulate either door singly or both together.

It may here be observed that this extreme facility of movement is the explanation of the remarkable durability of the Sluices constructed on the writer's system. Where no effort is required, it is clear that strains of all kinds, and the wear and tear consequent thereon are avoided.

The confidence which the writer thus expresses with regard to the easy control which he can provide is the outcome of long and patient experience in the construction of all kinds of Sluices for varying purposes and in circumstances of ever increasing magnitude and importance.

For instance, the Sluices already alluded to, as having been at work ten years without repair, are situated at Lough Erne, and control the whole water-shed of the country for 50 miles, and yet they can be so easily handled that a child can, and does frequently, make the necessary regulation, although the load on each four doors is 100 tons.

Again on the Manchester Ship Canal there are 120 of these doors for various purposes and of varying sizes. Thirty two of them are nine metres wide, and many of them are also eight metres high, and have a static load of 310 tons on each door. In one case there are 10 such doors in one group, for controlling the waters of the river Weaver; these have been at work and in the daily use for three years, without a hitch of any kind.

In every case, these large doors are moved easily by one man and therein lies their durability aud trustworthiness. Such results are not to be attained by any cheaper methods, and all such contrivances as doors on fixed rollers, doors with inclined faces, doors with partial flotation chambers, are entirely inapplicable to present case — the true way of obtaining control is to remove friction (and as far as possible displacement) and therein lies the writer's success.

It may be not out of place here to mention that the writer has lately been entrusted to enclose the waters of the river Thames by a series of his Patent Sluices. In this case, each door is 20 metres wide. One door is already erected in the Thames, and the others are in course of erection.

These doors are all moved by hand power only.

A set of Sluices for another River have been recently designed each door 12 metres wide and 13.5 metres high, total load 1,000 tons.

In conclusion, the writer begs to express the conviction that there is no part of this work which cannot be carried out with perfect confidence in its complete success, and there is no mystery in it: its magnitude requires only bold, skilful and liberal treatment keeping always in view, the great national character of the work and the supreme importance of its durability.

An estimate of cost is subjoined.

(Signed): F. G. M. Stoney, M. I. C. E.

Ipswich, July 7th, 1893.

Ipswich, July 7th, 1893.

W. WILLCOCKS, ESQ.

Inspector General of Reservoirs,

Cairo, Egypt.

DEAR SIR,

We have examined and discussed with Mr. Stoney the plans of proposed Sluices for the Nile Barrages and our estimate for each Barrage stands as follows : —

70 Sluices 2 metres×10 metres and lifting 10 metres under a head of 22 metres, also
30 Sluices of the same size and same lift, but under a head of 15 metres only.

To be made, delivered and erected at Assouan worked and maintained by us, at our cost, for a period of three years, for a total sum of One hundred and seventy eight thousand, eight hundred pounds, we finding all our own Cranes, tackle and appliances, but having the use of any rails and means of access to the site, it being understood that we are to erect our work only at such times as the site is kept dry for us (without cost to us) by any necessary dams and pumping. Such provision will no doubt be made for the construction of the foundations and masonry, and our work could be erected at the same time.

We are willing to enter into a contract to the above effect with all usual terms and conditions.

Your's truly,

(Signed): RANSOMES & RAPIER.

APPENDIX V.

DESCRIPTION AND STRENGTH OF EGYPTIAN STONES.

DESCRIPTION AND STRENGTH OF EGYPTIAN STONES.

The building stones in Egypt are Syenite, Nubian Sandstone and limestone of the tertiary formation. Specimens of the different classes of stone were sent to Professor Hudson Beare of University College London, to be tested and the following is an epitome of his report. His calculations were all made in pounds and square inches and I have reduced them to kilogrammes and square centimetres.

(1 lb. per square inch.............. = .07 kilogrammes per square centimetre).

(1 kilogramme per square centimetre = 14.2 lbs. per square inch).

CLASS OF STONE	WEIGHT OF A CUBIC METRE IN KILOGRAMS	CRUSHING LOAD IN KILOGRAMS PER SQUARE CENTIMETRE	ABSORPTION OF WATER PER CENT OF DRY WEIGHT	REMARKS
Limestone from Old Cairo	2560	1045	.80	All except the 5th were $2\frac{1}{4}''$ cubes. The 5th was a 3″ cube. The 2nd specimen had crystalline hollow spaces in interior.
	2560	801	1.09	
	2580	1121	1.27	
	2590	1051	.73	
	2590	1068	—	
	2760	1245	.75	
	2610	1056	.93	Mean of 18 cubes.
Limestone from the Tura quarries.	2310	367	4 27	All $2\frac{1}{4}''$ cubes.
	2330	523	4.35	
	2340	589	4.02	
	2430	566	2.36	
	2490	708	1.40	
	2380	551	3.28	Mean of 15 cubes.
Black Diorite.	2790	1279	·25	All 2″ cubes.
	2810	1348	.12	
	2800	1313	.19	Mean of 5 cubes.
Red Syenite.	2640	1307	.13	All 2″ cubes.
	2640	1530	.26	
	2640	1418	.20	Mean of 6 cubes.
Nubian Sandstone.	1850	152	11.16	All $2\frac{1}{4}''$ cubes.
	1860	112	9.91	
	1890	202	10.32	
	1950	264	9.87	
	1880	183	10.31	Mean of 12 cubes.

Limestone from Old Cairo. This is a dense crystalline stone, slatey grey, greyish white and creamy in colour ; the greyish white was the densest and strongest.

Limestone from Tura. This is a semi-crystalline stone, not dense, creamy in colour ; the denser the stone the stronger.

Black Diorite from Assuân. A micaceous diorite with rather fine crystals.

Red Syenite from Assuân. A granite with large pink flat cristals of felspar.

Nubian Sandstone. This is a coarse silicious sandstone, with little cementing material, of a whitish colour. The denser the stronger.

From each block of Old Cairo and Tura limestone and Nubian sandstone 9 cubes were sawn out and the bed faces of each cube rubbed smooth and parallel. These were all $2\frac{1}{4}$ inch cubes, except from one block from Old Cairo which had sides of 3 inches.

From the Syenite and Diorite blocks rough pieces were cut out by chisels and wedges and dressed to size by chisels and then finally rubbed down to 2 inch cubes.

The following tests were made : density, absorption of water, crushing strength.

Density and weight. Each specimen after thorough drying was carefully weighed, its volume calculated and therefrom its density.

Absorption of water. Two specimens of each block were, after weighing, immersed in distilled water at air temperature, and kept there for 7 days. They were then taken out, at once wiped dry and reweighed. The gain of weight represents the water absorbed.

Crushing strength. The bed faces of the cubes were strickled over with a thin layer of plaster of Paris ; these were then rubbed quite smooth and parallel, and in testing, these faces were applied directly to the dies of the machine. All the cubes were tested when quite dry. The load was gradually increased from *Zero* to crushing load, if any cracking occurred at lower loads than the actual breaking load, the fact was noted.

Old Cairo Limestone. The heaviest block had the greatest crushing strength. The cubes began to crack at loads which were 50 per cent of the crushing loads, differing very much in this respect from the granites. The water absorbed was small but distinct.

Tura Limestone. The densities vary from 2.31 to 2.49, and the crusching strength from 367 to 708 kilograms per square centimetre. The denser the stone the stronger. The densest stone approaches those from Old Cairo. The greater the density the less the water absorbed. The cracking load is not much under the breaking load.

Black Diorite from Assuân. — Red Syenite from Assuân. The Syenite is less dense than the Diorite, but it is distinctly the stronger stone. These granites are practically non-absorbent. The dampness of surface cause the trifling additional weight.

The cracking and crushing load is one.

The Diorite is very difficult to work and refuses to split at the wedge lines. The Syenite is easy to work and splits along the wedge lines.

Nubian Sandstone. The denser blocks are *much* stronger than the less dense. The cracking and crushing weight is one. This stone is exceptionally poor and absorbs an extraordinary quantity of water. The stone is more like an English Oolite than a sandstone. A series of 4" cubes when crushed gave a compressive strength over 50 per cent in excess of the $2\frac{1''}{4}$ cubes.

The coefficients of elasticity of Old Cairo and Tura limestone are 500,000 and 350,000 kilogrammes per square centimetre respectively. — The same as hard English dolomites.

APPENDIX VI.

STRENGTH OF EGYPTIAN MORTARS.

STRENGTH OF EGYPTIAN MORTARS.

In order to test the strength of the hydraulic mortars of Egypt, a continuous series of tensile and compressive experiments has been made. The tensile tests were made with briquettes of a minimum section of 1 square inch, while the cubes which were crushed had a side of 5 centimetres. The crushing machine was not a delicate one and needed frequent adjustments; these adjustments were often the cause of the cubes being broken quite independently of any weakness in the mortar. We also found it were difficult to get the two surfaces which touched the crushing boards perfectly smooth and parallel to each other Taking the above into consideration, I have been able to place little reliance on the compressive experiments, and have preferred multiplying the tensile strengths by 10, and considering the results as the compressive strengths.

The limes tested were the following: —

Fat *Cairo* lime from the Bata el Bakkar quarry.

Fat *Silsila* lime from the Raghama quarry, of a *white* colour.

Fat *Silsila* lime from the Raghama and Fatèra, of a *dark* colour.

The limestone was burnt and slaked, and then used fresh. The puzzuolana was made from rich black Nile deposit, burnt to a dark red colour, and then ground and sifted. It was likewise used fresh. The sand was quartz sand from the desert. The puzzuolana classed as coarse was sifted through a sieve of 400 meshes to the square inch, and that called fine was sifted through a sieve of 900 meshes to the inch. The coarse sand passed through a sieve of 400 meshes to the inch, but was retained on a sieve of 900 meshes to the inch. The fine sand was sifted through a sieve of 900 meshes to the inch.

The slaked lime and pozzuolana were mixed dry in the proper proportions and then had water added to them. A portion was taken from the mass, stirred in a mixer for two hours, and then made into briquettes. The briquettes were left in the moulds for 24 hours, then put into damp sand for 6 days, and finally into water for 6 months less a week. At the end of 6 months from the day of moulding they were broken. The mass of the mortar was put into metal troughs and kept wet, and briquettes were made daily from it till it was expended. In some cases 18 days elapsed between the making of the mortar and the moulding of the briquettes.

Twelve briquettes were always made; six were broken after 6 months, and the rest will be broken when 12 months have elapsed. So far we have broken after 12 months, none of the briquettes made of the good proportions and good ingredients mentioned in the table; but judging from the results with the inferior mixtures, we may fairly anticipate a gain of 50 per cent in the strength of the mortars after 12 months as compared to the 6 months tests.

The best proportions for the ingredients have been found to be as follows:—

1 part by measure of slaked fat lime.

1 $^1/_2$ parts of measure of fine pozzuolana.

1 part by measure of coarse desert sand.

By way of comparison, briquettes and cubes were made of the well known Theil lime from France, of which especially good specimen bags were ordered. This lime is so well known and appreciated, that the comparative tests prove conclusively that in Egypt we have the materials for manufacturing a really first class hydraulic mortar.

Hydraulic mortar made of the Cairo lime is stronger if used 10 days after manufacture than is used fresh. Both the Silsila lime mortars are distinctly stronger however if used fresh, than if they are allowed to stand even for 24 hours. These latter mortars decrease in strength steadily as they get older.

Briquettes and cubes are also made of mixtures of 4 lime, 8 sand and 1 cement, and 10 lime, 5 sand and 1 cement. These were the proportions of the mortars used at the new Puentes and Villar dams in Spain (mentioned in Appendix I, pages 12 and 13). It is very evident from the tests recorded at the bottom of the table that the Egyptian limestones are not at all suited for mortars made of these ingredients.

Finally, briquettes were made of finally pounded unburnt clay, sifted through sieves of 5,000 meshes to the inch, and mixed with lime and sand, or a lime alone. The best proportion was 2 lime, 1 sand and 1 unburnt clay, but the tests recorded at the bottom of the table prove that the use of unburnt clay is attended with risks and results in a mortar of mediocre strength.

Rubble masonry at the dams could be constructed with pozzuolana mortar at a rate of 45 piastres per cubic metre, while in the estimates I have entered 80 piastres, 100 piastres and 150 piastres per cubic metre, according to the proportion of the face work which is to be built of cement mortar. The rates allowed are accordingly excessively liberal.

Tensile strength of mortars in kilogrammes per square centimetre.

BRIQUETTES TESTED SIX MONTHS AFTER MANUFACTURE.

(Multiply by 14.2, to obtain pounds per square inch).

AGE OF MORTAR IN DAYS	NEAT THEIL LIME FROM FRANCE	1 THEIL LIME 3 COARSE SAND	1 THEIL LIME, 3 FINE SAND	1 CAIRO LIME 1 1/2 POZZUOLANA FINE	1 CAIRO LIME 1 1/2 POZZUOLANA COARSE	1 CAIRO LIME 1 1/2 POZZUOLANA FINE 1 FINE SAND	1 DARK SILSILA LIME 1 1/2 POZZUOLANA FINE	1 DARK SILSILA LIME 1 1/2 POZZUOLANA COARSE	1 DARK SILSILA LIME 1 1/2 POZZUOLANA FINE 1 COARSE SAND	1 WHITE SILSILA LIME 1 1/2 POZZUOLANA FINE	1 WHITE SILSILA LIME 1 1/2 POZZUOLANA FINE 1 FINE SAND
fresh	24	16	8	15	16	16	21	20	14	20	18
1	..	..	..	14	16	18	19	14	12	14	16
2	..	..	..	12	19	17	17	14	9	12	13
3	..	..	..	17	17	21	15	14	9	16	14
4	..	..	..	15	17	19	16	12	11	17	14
5	..	..	..	15	17	17	17	12	12	16	14
6	..	..	..	12	17	17	19	..	12	15	13
7	..	..	..	12	15	17	18	..	..	18	13
8	..	..	..	15	14	20	13	..	..	15	13
9	..	..	..	15	16	20	11	..	..	12	12
10	..	..	..	16	17	23	11	..	..	12	12
11	..	..	..	..	..	..	12	..	..	14	12
12	..	..	..	..	..	..	14	..	..	16	11
13	..	..	..	..	..	..	12	..	..	14	..
14	..	..	..	..	..	..	11	..	..	15	..
15	..	..	..	..	..	..	11	..	..	13	..
16	..	..	..	..	..	..	12	..	..	12	..
17	..	..	..	..	..	..	12	..	..	14	..
18	..	..	..	..	..	..	12	..	..	..	..

Briquettes of 10 Lime, 1 Cement and 5 Sand were broken at 8 kilogrammes per square centimetre.
» 4 » 1 » 8 » » 7 » » »
» 2 » 1 Sand, and 1 unburnt stiff clay were broken at 10 kilog. per square centim.
In the case of the last briquettes, the mortar had to be put into the moulds immediately after it was made, as the least delay resulted in the briquettes either cracking or melting away when placed in water.

APPENDIX VII.

GEOLOGY

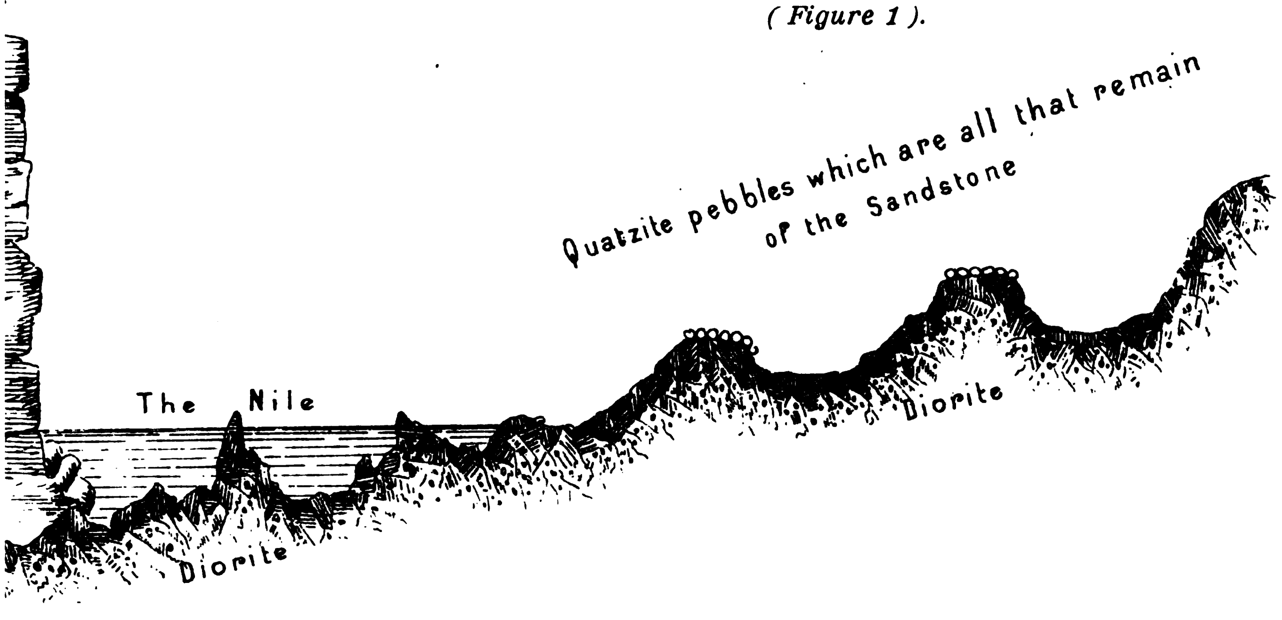
OF THE NILE VALLEY FROM WADY HALFA TO CAIRO.

GEOLOGY OF THE NILE VALLEY FROM WADY HALFA TO CAIRO.*

The second Cataract.

The second Cataract, or the Batn el Haggar terminates at the Khor Mûsa, about 8 kilo- ıetres South of the cantonments at Wady Halfa. Some fifty kilometres South of Halfa is ırras, the Egyptian frontier station and the most southerly point visited by the Reservoir urvey party. Between Sarras and Khôr Mûsa the rocks are plutonic, principally diorite. he hornblende is generally in excess of the felspar, and the diorite has a very black ppearance. There is an occasional outcrop of syenitic diorite, but the latter stone is rare. etwen Sarras and Abka, on a length of 30 kilometres, the Nile has a comparatively clear ıannel, open to navigation all the year round. North of Abka, the river is broken up into umerous channels and there is a series of very severe rapids. The diorite has a general fall estwards and disappears under Nubian sandstone on the left bank from near Akba north- ards. The river has been working away in a westerly direction and is engaged eating way the sandstone. Plates 30 and 31 contain cross sections of the possible sites for dams in ıe second Cataract North of Sarras. Dams here would be very expensive while the quantity water contained in the reservoirs would be inconsiderable. As seen from the rock of busir, the second Cataract has a mean appearance. The sandstone hills on the west are

(Figure 1).



Cross section of the Nile Valley

unded off sandy knolls and featureless to a degree, while the dyorite on the East looks like aps of broken up coal at countless pits' mouths. The river itself runs in deep narrow annels between black islands, covered here and there with a scanty vegetation. The diorite

* Professor Sickenberger has kindly read and corrected this Appendix and supplied me with the bles at the end and a small Geological map by Professor Mayer Eymar who has studied and named me of our fossils.

is generally very inferior and so finely laminated that it weathers very easily. Occasionally however, the laminae are coarse and compact and look like dark slates. Large blocks are rare. Specimens of all the different rocks meet with between Sarras and Khôr Mûsa have been collected and deposited in the geological museum formed by Professor Sickenberger at the School of Medecine.

Plutonic rocks between Halfa and Assuân.

From the foot of the second Cataract to Assûan, the foot of the first Cataract, the Nile traverses 310 kilometres of Nubian sandstone and 40 kilometres of plutonic rocks. The plutonic rocks are met with at the following points: —

Abkhôr (67 kilometres from the first Cataract); here there is a slight outcrop of laminated diorite in the bed of the Nile.

Kalabsha (kilometres 54 to 40 from the first Cataract); here we have in the bed of the river a considerable quantity of syenite * and a quartz diorite which has the appearance of basalt. Pegmatite and porphyry are also met with. The diorite is very hard and brittle, and the stone at the proposed site of the Kalabsha reservoir dam is generally good and durable, though the Nile has cut through the barrier without leaving any trace of a cataract.

Debôd to Assuàn (kilometres 30 from the first Cataract to the Cataract, and 5 kilometres of the first Cataract); the rocks here are diorites and schists improving in quality as one approaches the first Cataract where there is an extensive outcrop of syenite and quartz diorite. These rocks are very hard and compact and well suited for the site of a reservoir dam**. Figures (2) to (10) give rough sketches of the different classes of rocks met with between Assuàn and Halfa, while the two water colour drawings in the general atlas give a very correct idea of typical granite and sandstone.

Nubian sandstone.

The Nubian sandstone is a silicious sandstone, sometimes white, but more often discoloured red by iron; it is occasionally yellow. Generally speaking the whiter to rock, the better. The strata are either horizontal or very nearly so. The layers of sandstone have interposed between them a syenite marl of a violet colour, the decomposition of the felspar of the syenites and diorite which form the plutonic rocks of Nubia. These violet coloured strata are very thick and numerous at Wady Halfa and decrease gradually as one advances northwards where their place is taken by a yellow marl. The stratum of sandstone immediately above the plutonic rocks is composed of very coarse pebbles as large as hens'eggs. The pebbles are principally quartz, clay slate and flints proving that the Nubian sandstone is not earlier than cretaceous. The stratum above this is a very coarse sandstone which crumbles away when touched, but as one ascends vertically the stone becomes finer. There is a complete absence of fossils. Very occasionally strata are met with which contain traces of salt or lime, but these two substances are very rare indeed.

The violet coloured earthy strata crumble away when exposed in a vertical section, but where a stratum comes to the surface, the uppermost layers become covered with black blisters which increase in size and form eventually round hollow black balls which cover the face of the desert. These are the infernal bombs which Sir Samuel Baker describes so graphically in his account of the desert journey from Abu Hamed to Korosko. There is also a stratum of red sandstone which on coming to the surface hardens into verified looking masses. Some of these bombs and stones are of the most fantastic shapes. I have deposited many specimens in the Museum. Some are like vitrified bricks, some are like petrified wood with hollow cores, others are like hollow cannon balls, and others again are like hollow fish. Outside is a hard metallic substance and inside is sand. They must have been caused by the action of the sun through the long hot dry Nubian summer. One can see the blisters and blebs in every stage of formation, as one goes through the desert.

* By syenite I mean Assuân granite.

** The site of the cataract is covered with deep cups worked in the granite by the play of boulders and pebbles which cannot escape.

Whenever these bombs and balls cover the hills, there is no flying sand and the deserts are clean, the Nile valley is cultivated and there is no fear from sand-drifts. Where these metallic substances do not exist the sandstone hills are in full decay, and the sand flying of the hills fills up the valleys, and we have the ideal wilderness. The western bank of the Nile is buried under sand and cultivation is confined to the right bank.

In the School of Medecine will be found specimens of the different strata of Nubian sandstone from Halfa to Silsila. At nine places I have given the positions of the strata in a vertical plane referred to mean sea, and in a horizontal plane referred to the 1st Cataract.

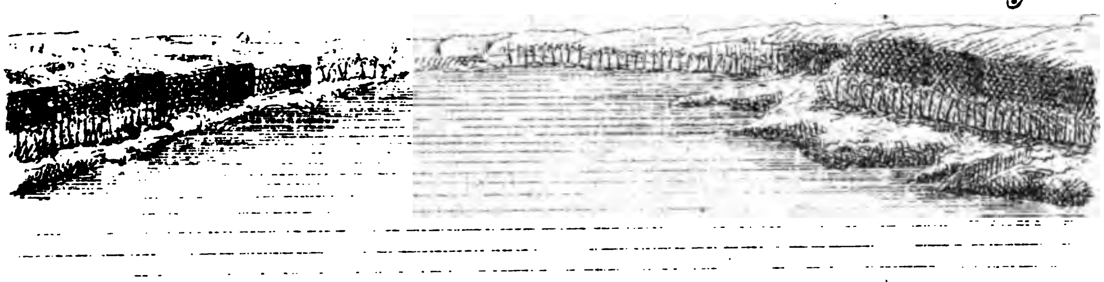
The nine places are: —

Abusîr rock, at the second Cataract.
Sahàba, about 10 kilometres north of Halfa.
Abu Simbel.
A hill to the north of Korosko.
Syàla station.
Abhòrr station.
Ambarakab station.
The 1st Cataract.
Gebel Silsila.

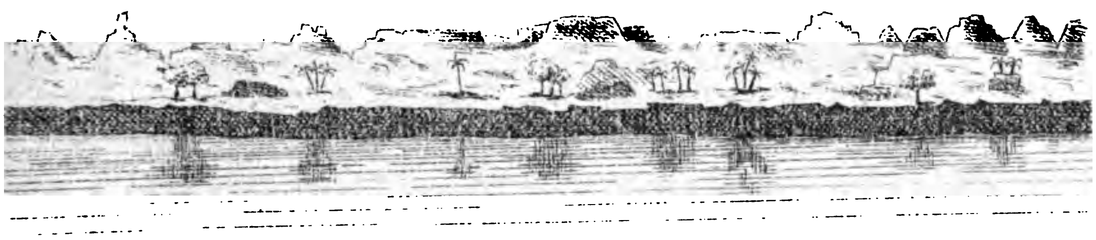
Fig. 2

Typical Granite

Fig. 3

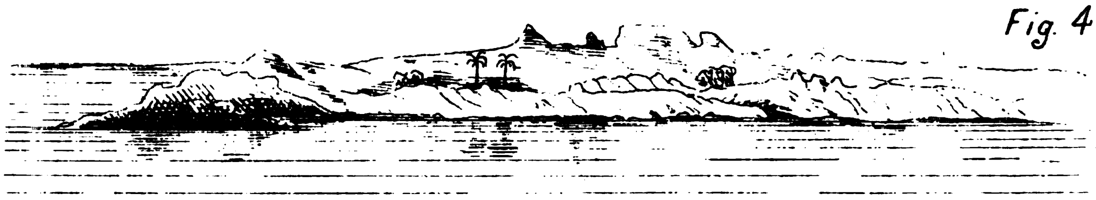


Typical sandstone not in a state of decay



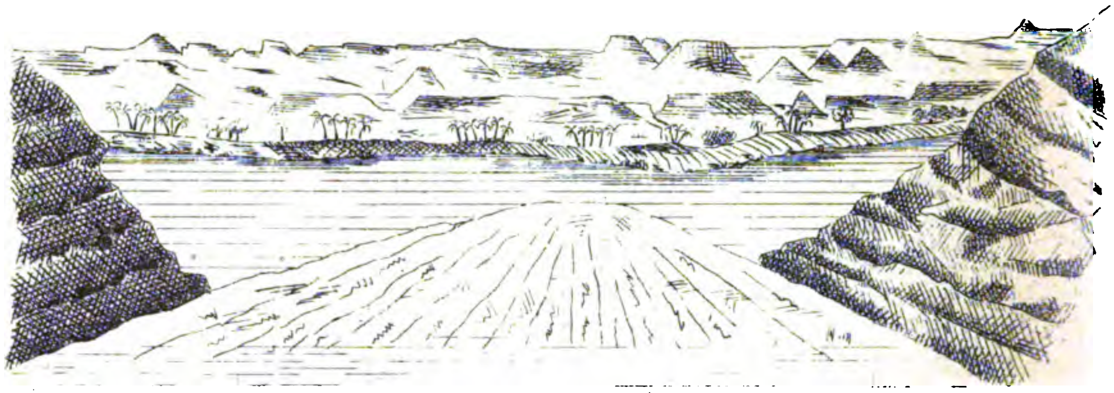
Typical decaying sandstone

Fig. 4



Typical decayed sandstone

Fig. 5



Sand drift at Abu Simbel

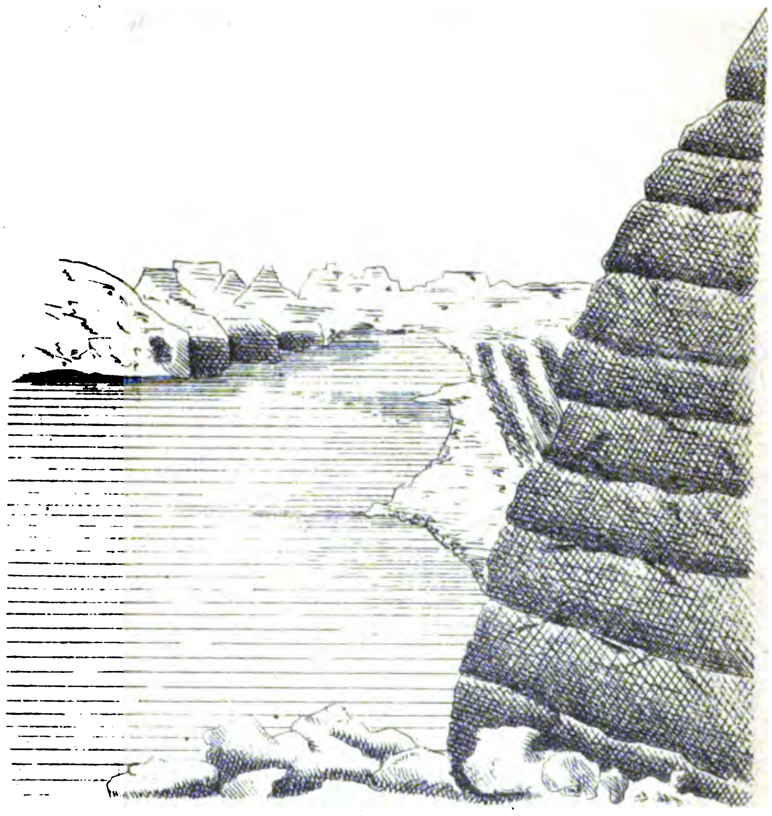
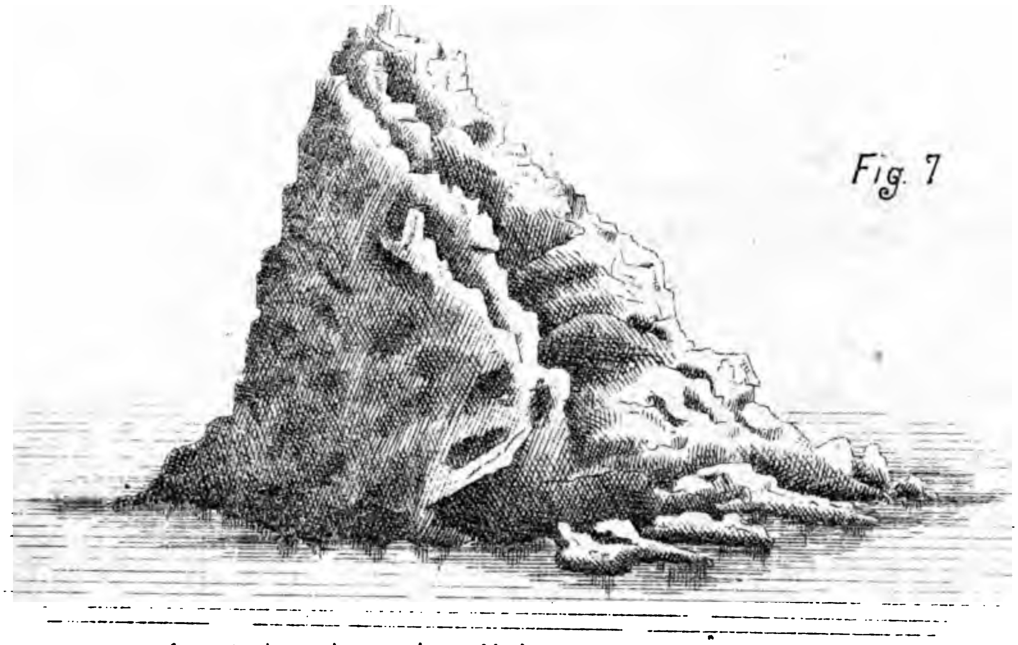


Fig. 6

Abu Simbel sandstone

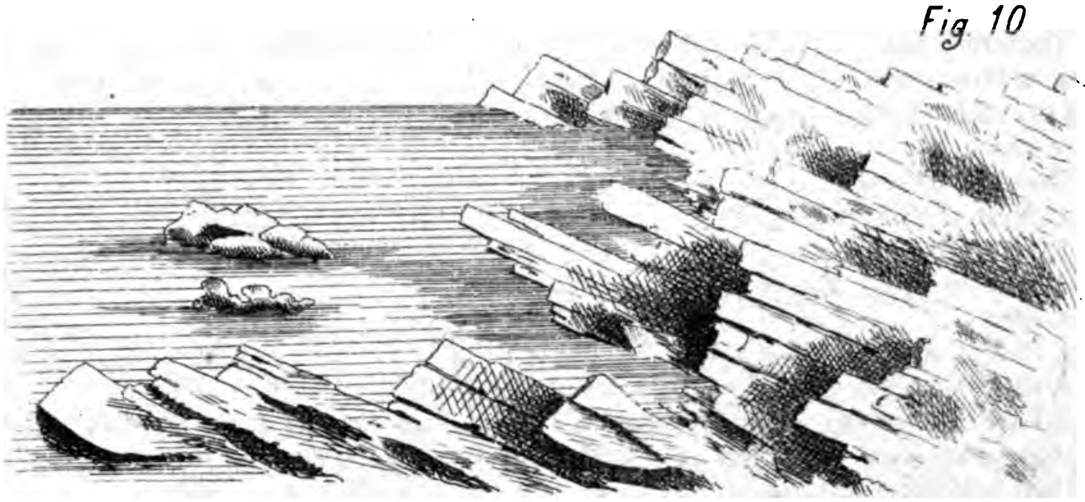


An island in the Nile near Kalabsha
(Quartz Diorite)

Possible site of Kalabsha Reservoir Barrage
(Syenite & Diorite)

Possible site Assuân Reservoir Barrage
(Diorite & Syenite)

Fig. 10



Abkhor (Diorite)

The Nile valley from Halfa to Luxor. Before describing in detail the narrow trough of the Nile itself, it may be as well to give a general idea of the Nile valley from Halfa to Luxor, as the existing maps are lamentably incorrect. On the hydrological map of the Nile valley from Halfa to Silsila, there is a small map of this tract on a scale of $\frac{1}{1,500,000}$.

From Abu Simbel northwards, the valley is bounded on the left by a high limestone plateau, known as the "Sin el Kidab"*, which is at first 90 kilometres away from the Nile, but gradually approaches until at Assûan it is 40 kilometres away, and from Gebelain northwards comes close to the river. Opposite Esna, there is also on the right bank of the river a similar limestone plateau, so that at this point the plateau is traversed by the Nile, and the hills about Gebelain bear traces of the struggle of the river to eat its way through. Gebelain evidently was the site of an ancient and considerable cataract. The reduced level of the Nile in flood is at Ibrîm 116 metres, and at Assûan 94 metres, while the general level of the plateau is 450 metres, and its highest point, the Garra Hill opposite Assûan, is 540 metres above sea level. The dip of the strata everywhere is North-West. On this plateau are the Kurkur and Dunkul wells. At the top of the Garra Hill are some 90 metres of lower Londinian limestone, then a 5 metre belt of Suessonian yellow clay with *Rhynopygus abundans* of Mayer Eymar, and then about 230 metres of foliated marl of the cretaceous formation with a thick belt of *Ostrea Overwegi* in the middle. Below these stretches away the sandstone plain. Near Garra the sandstone is calcareous, but as we approach the Nile we have the ordinary

(Kurkur). silicious Nubian sandstone. The Kurkur wells are at the east end of the so called Kurkur oasis, a basin on the top of the plateau, where there are a few acacias and dôm palms. There

(Dunkul). is always an abundance of good water at Kurkur. The Dunkul well is a cup on the top of the range. There is very little water here and one cluster of dôm palms, though about 5 kilometres to the north there is a valley with numerous Sallim acacias. Between Garra and Dunkul the upper crust of limestone is very hard and almost metallic, while at places it is of a reddish colour with numerous oyster shells imbedded in it. This limestone has been described as porphyry by some travellers. The two sections of the Nile valley at Ibrim and Assûan, which accompany the plan, show how heavy the denudation has been. At Assûan it must be 60 kilometres $\times$ 300 metres, and at Ibrîm 100 kilometres $\times$ 150 metres. The hard limestone cap has been degraded slowly, but the foliated marl was made to be eaten away; it has no consistency, and it is only when it dips below the level of the Nile at Gebelain that we have traces of a cataract.

* "Sin el Kidab" means "the liar's tooth", and is used by the Arabs to define this plateau, as its great height makes it appear closer than it really is, and if you think you will reach it in one day, it will take you a day and a half.

The arrow heads on the plan show the direction of the rainwater to-day. It rains once in two or three years. The watershed is close to the Nile on its left bank, but on the right bank the whole of the desert drains into the Nile through seven main Khôrs and numerous minor ones.

The seven main channels are : —

1. South of Wady Halfa.
2. South of Abu Simbel.
3. South of Ibrîm.
4. Korosko.
5. Khôr Allaki at Dekka. This is the largest of all.
6. Khôr Demhit some 40 kilometres South of Assûan.
7. Khôrs Kereit and Shait at Fatèra near Gebel Silsila. On the longitudinal section, I have given an idea of hills bordering the right bank on the Nile, showing how completely they have been degraded in places.

The only outcrop of granite on the left bank of the Nile which I have seen is one to the West of Ibrîm and shown in plan and section.

(Kom Ombo).

Between Assûan and a point a few kilometres to the South of Esna (where the Nile may be said to enter the limestone hills which skirt it as far as Cairo) the river is between sandstone hills except at two places, the plain of Kom Ombo and the plain of Edfu. These two plains were ancient deltas of rivers coming down from the high granite and porphyry ranges which skirt the Red Sea, and flowing into the upper cretaceous and Eocene sea in which the "Sin el Kidab" foliated marls and limes where being deposited. There are solitary limestone hills still standing in the two plains surrounded by sandstone. The sands and clays of the Edfu and Kom Ombo deltas of an age anterior to the Nile are covered with pebbles of porphyry and granite brought down from the Red Sea range. These stones have no affinity to those met with at Assûan, Kalabsha or Halfa.

The trough of the Nile from Halfa northwards.

Descending the Nile from the second Cataract, we find it flowing between sandy degraded hills past the Wady Halfa fort situated in a plain of Nile deposit. Here the river in winter and summer, forms numerous islands, and is inclined to leave the right bank on which Halfa is situated. Some spurs have been put in on the left bank to improve navigation.

At Sahâba Hill (kilometre 331*) on the right bank of the Nile some bold hills approach the river. From these hills geological specimens have been collected. The strata of violet clay are very extensive indeed. There is one thin stratum which contains traces of common salt. After Sahâba, the sandstone hills on the right leave the Nile, and there is an extensive deposit of shingle 12 kilometres in length and a half kilometre in width, dividing the cultivated plain of Deberra into two parts. The shingle is doubtless ancient detribus from the second Cataract.

The left bank of the river continues low and mean and covered with sand drift. Here and there are evidences of ancient cultivation, but as the struggles of the inhabitants against the sands drifts have been intermittent through centuries, while the action of nature has been unceasing, the cultivated land dwindled to a minimum.

Faras island at kilometre 308 is covered with vegetation. The navigable ** channel here needs considerable improvement. The hills along here are low and insignificant. At kilometre 296 and again at kilometre 294 the navigable channel is very narrow and winds from side to side of the river with dangerous rocky islands which further complicate the navigation.

In my book on Egyptian irrigation I had stated, that I considered the great training spurs in the Nile between Assûan and Halfa, as put it for the sake of creating soil on the

* The kilometrage on the plan and the longitudinal section, to which reference is made, is reckoned from the head of the 1st Cataract, North of Philæ, up the centre line of the river.

** Navigation at low Nile is always contemplated. At high Nile of course there are no difficulties. Navigation here is very important, as it is the only means of communication between the military posts of Assûan and Halfa.

hands of the river, but now that I have seen them at low water, I think they were put in for river training principally. They insured a deep navigable channel throughout the year, and kept the southern fortresses of Nubia in communication with Syene. These spurs should all be repaired and thoroughly renewed.

From kilometre 295 to kilometre 291 is an extensive sandy plain covered on the right bank with strange conical sand hills.

At kilometre 291, the river infringes on some bold sandstone hills and sweeps round their bases. At kilometre 281, the same class of hills is met with on the left bank and here stand the giant colossi of Rameses and the magnificent temple of Abu Simbel. Here a geological section of the sandstone was made. The rock is better than what is generally met with and the strata of violet coloured earth are few in number. One of these belts of earth passes along the knees of the colossi which are considerably degraded. Above the temple there are two broad belts of earth, which in decaying where leaving the layer of sandstone between them projecting forward in a dangerous manner. One big fragment from this stratum of rock had already in the past fallen on the head of the second colossus from the left and completely destroyed it, while the existence of the first colossus on the left was threatened by the fellow of the rock which fell before. By the falling of small fragments of rock the monkey cornice at the top of the temple had been well nigh destroyed and the crowns of the standing colossi had been broken. The whole hill needed to be thoroughly done up with masonry. The matter was brought the notice of Woodhouse Pasha, the Commandant of the frontier, who took the matter up warmly and hand the whole hill thoroughly cleared and the loose rocks cemented by a part of English soldiers under Captain Johnson. (Abu Simbel).

The sand drift which was partially removed in 1890 from the foot of the temple is fast returning and destroying the view of the Temple. The drift is not a very long one and, if it were once entirely removed, it would take a very long time indeed, before the sand could collect again. Between the two hills there is a sun-dried brick wall which keep up the sand, prevents the Nile flood from attacking it and turns the sand into the temple. If this brick wall were removed and the Nile deposit near it cut away or cleared of all debris from the temple, the Nile itself in high flood would cut away the drift and improve immensely the appearance of the temple. I think L. E. 100 would suffice for this work.

After Abu Simbel the high hills leave the river, and with the exception of a reach of a cultivated land on the right bank, the Nile flows between low rugged hills as far as the southern limit of Toski village (kilometre 297). Near Toski the high hills appear in the distance, while the foreground on the left is singularly low, flat and sandy. Opposite Toski village, the deep channel is along the right bank, where the old spurs have been turned much to the inconvenience of the navigation. The spurs should be renewed.

Near Ibrîm Fort (kilometre 233) on the right side, a singularly bold range of sandstone hills is met with, and the views of the Nile are impressive. From here on to Korosko the hills on the right are generally bold and high, while the Nile bank from kilometre 228 to kilometre 199 past Ibrîm and Dèr, is well cultivated. Ibrîm and Dèr are the two richest villages between Halfa and Assûan. On the left bank also there is a considerable amount of cultivation, while there are extensive flat plains for some 3 kilometres away from the river. The presence of wells on this plain indicates an ancient arm of the river which is now silted up. Some high hills are met with at kilometre 198 of the river on its left bank, but these also immediately recede from the river. From kilometre 190 to kilometre 179 on the right bank, past the town of Korosko (kilometre 187) there is a range of very high sandstone hills.

The navigation on the long curve opposite Dèr (kilometre 207) is very difficult and training works should be undertaken here to deepen the summer channel of the Nile. This is the worst reach between Halfa and Assûan.

At kilometre 202 on the left bank of the Nile, is the interesting temple of Ameda, with some very perfect carvings, which is fast going to wreck. Something should be done to preserve this temple.

As one leaves the Nile here and enters the deserts on the left bank of the river, one traverses sandy plains strewn thick with fossil trees. There are half a dozen very good specimens of this wood in the School of Medecine. Out of the sandy plain rise countless pyramids of sandstone which remind one very forcible of Gizeh, while the low decayed mounds in the mirage look exactly like sphinxes. A mirage is not a reflexion, but a repetition, and it is with difficulty one persuades oneself hat there are no sphinxes at the feet of the pyramids one sees.

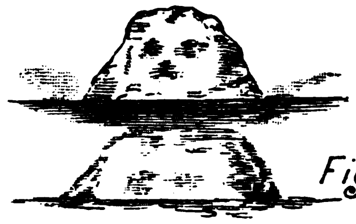


Fig. 11

From a hill near kilometre 184 a series of geological specimens has been collected. This is the hill sketched by Mr. Henry. A cross section of the hill would have been something like this (figure 12). For 70 metres up from the watersedge the hill is composed of a very coarse red sandstone in strata varying from 15 metres in thickness to 1/2 a metre, with two very distinct broad belts of the violet coloured earth Above 70 metres in height the hill could not be examined as the surface was covered thick with the silicious sinter.

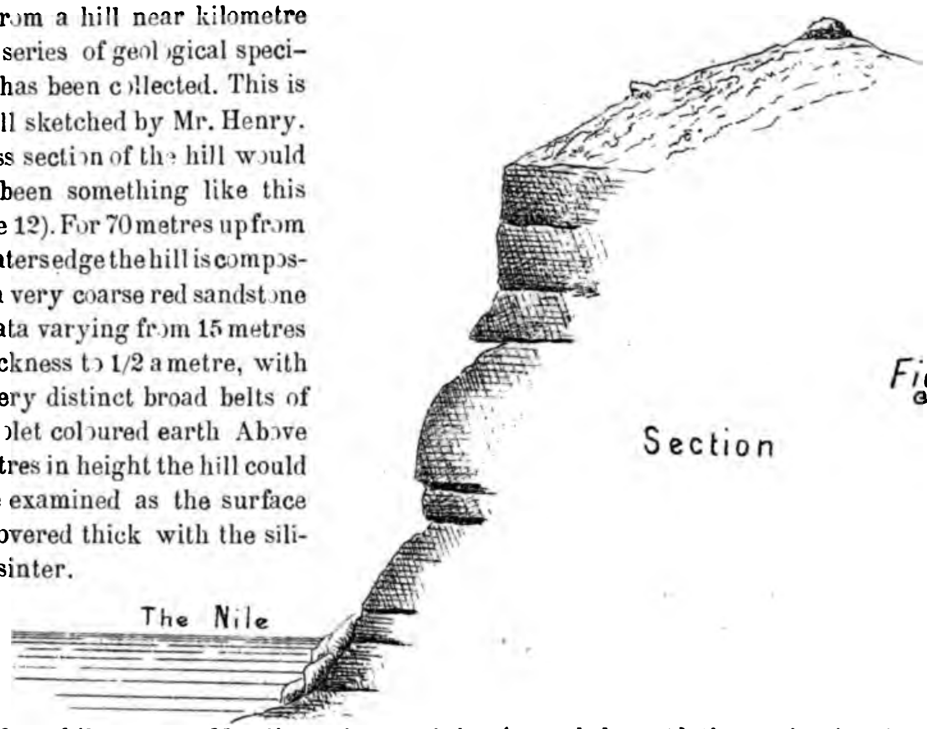


Fig. 12

About kilometres 177 a little river training is needed to aid the navigation in summer.

From here on to Syâla (kilometre 130) there are alternating very high and moderately high hills on both banks of the Nile with occasional patches of cultivation. Near Syâla the clay is mixed with a little lime and this earthy matter (unburnt) is used at Korosko instead of lime.

From kilometre 130 to kilometre 100 with slight interruptions, the left bank of the river is very flat and sandy. The sand hills have become completely degraded, Here and there a mound of large pebbles of porphyry and quartz is all that remains of what must have once been a very high hill. The plains may be said to be strewn with the skeletons of hills. They are very dismal. From kilometre 115 to kilometre 103 on a mean width of 1 kilometre, is the plain of Decca composed of Nile deposit. The wells here indicate that an ancient arm of the (Decca) Nile has been silted up. The plain is on an average 1.00 metre above high flood. It is cultivated in patches. So far the left bank of the Nile; on the right bank of the Nile there is much the same appearance of desert, except that the general level is much higher. At kilometre 113 on the right bank is the Khôr Allâki which drains whatever rain falls in the deserts between this and Abu Hamed nearly. The presence of gold in the bed of this stream led the ancients to image that the catchment basin of this stream contained gold. None of the quartz reefs in the plutonic hills near the Nile contain gold. They are too far removed from the centre of eruption. At kilometre 105 is the Gebel Hyata on the right bank, a low but very prominent hill.

From kilometre 100 to kilometre 55, the Nile flows between gradually rising hills of compact sandstone with fairly decent cultivation on both banks though in very narrow strips.

At kilometre 67 is an outcrop of granite on a length of 1 kilometre. This granite is very inferior and the Nile flows through it without any appearance of a rapid. At kilometre 58 on the right bank is the Khor Rabma which drains large tract of desert. At kilometre 57 on the left bank is the Kalabsha temple on the tropic of Cancer.

The quarries here give a very fair white sandstone.

From kilometre 55 to kilometre 49 is an outcrop of granite. There are numerous islands in the Nile. Plates 11 and 12 give plans and sections of this part of the Nile. It is a possible site for a reservoir. At kilometre 49 is the Kalabsha gate of the Nile, 150 metres wide and 40 metres deep in flood.

From kilometre 49 to kilometre 29 the Nile traverses very compact sandstone with good quarries at Taifa and Gertassa. The Philæ Temple was built with this stone. The cultivation on both banks of the river is good and the peasantry are fairly prosperous. The depth of the water in winter and summer is insignificant and the Nile needs frequent spurs, notably near kilometre 36 where navigation is very difficult.

If it is permissible to build reservoir dams on sandstone, there is not a bad site near the Gertassa temple at kilometre 40.

At kilometre 37 is the Khôr Demhit which drains the Bargat Tukham plain, in which is the Um Hibal well. Just south of the Khôr Demhit junction is the site where discharges are taken for reference to the Assûan gauge.

From kilometre 30 to kilometre 0, and 5 kilometres beyong that to Assûan, the river flows between granite hills. These last five kilometres constitute the first Cataract of the Nile.

At the foot of the first Cataract, on Elephantine Island, opposite Assûan stands the Assûan gauge; and as we descend the river from here, all kilometres will be referred to this gauge. The kilometrage itself has been measured down the centre line of discharge of the Nile in flood.

The Garra hill as seen from the sandstone plateau overhanging the Nile at Assûan has the appearance of the table mountain shown in figure 13, while figure 14, is a nearer view.

Fig. 13

Garra Hill from the Nile

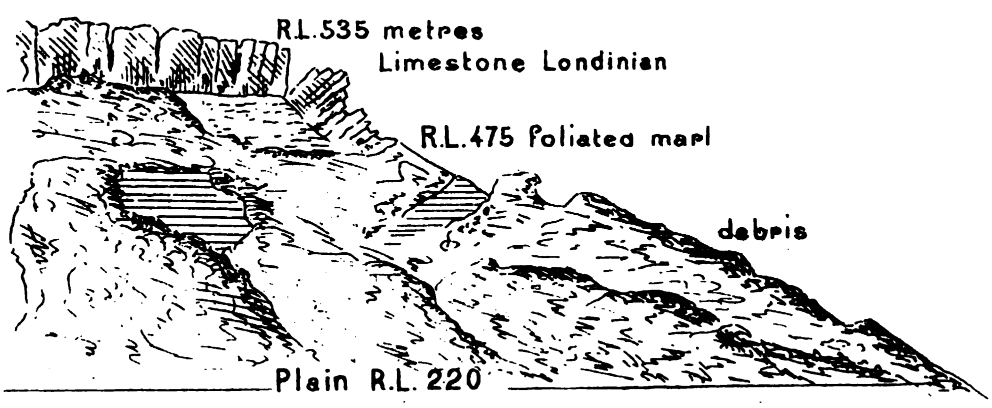


Fig. 14

Garra Hill

The degradation of the sandstone hills by the sandy desert winds if for ever going on, and occasionally the removal of a great part of an underlying weak stratum has a strange effect. Figure 15 gives the appearance of a rock on the Assûan Berber caravan road some 20 kilometres out of Assûan.

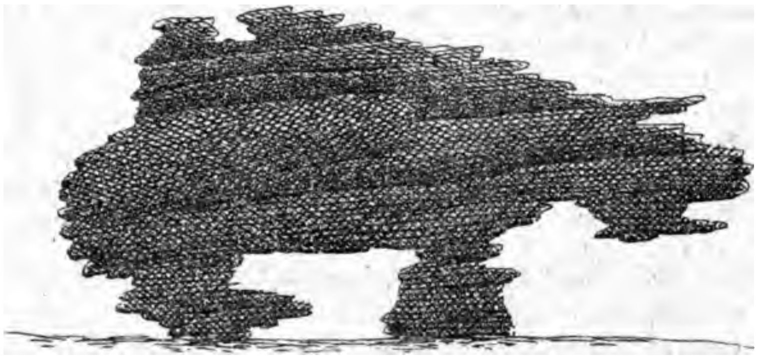


Fig. 15

Decayed Sandstone near Kult el Nus
South of Assuan

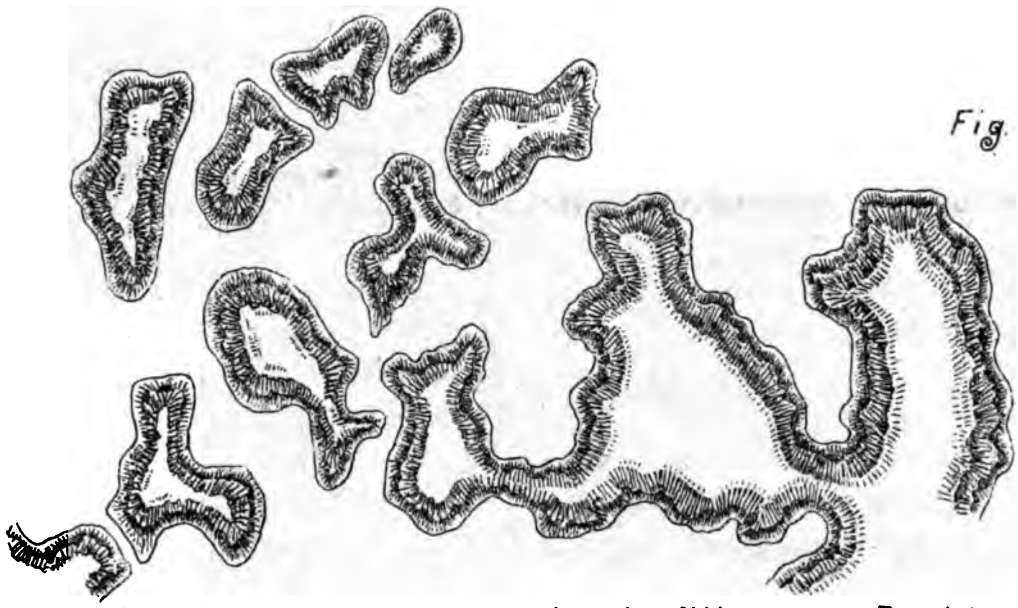


Fig. 16

Course of Sandstone eaten away by the Nile near Bimbân (action sill going on). Stones like these lie on the top of the rounded hills in this locality also showing that the Nile was once there

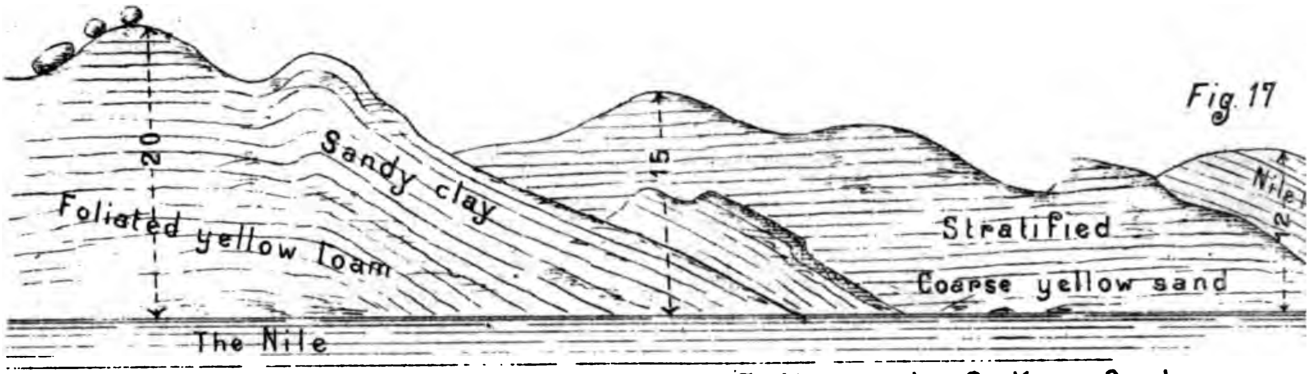
About 15 kilometres* to the North of Assûan is the Khôr Abu Suhêra on the right hand, a wide deep rent in the sand stone hills, and opposite it on the left is the Khôr Kumbania.

The Nile has cut across this ancient stream without obliterating it.

About 20 kilometres beyond the Khôr Abu Suhêra, we enter the Kom Ombo plain with Nile deposit 12 metres above the maximum flood level of to-day. About 8 kilometres downstream of the Kom Ombo temple, on the left bank of the Nile, is a very good section (Figure 17) (Kom Ombo)

* All distances are now referred to the Assûan gauge.

showing the relative positions and depths of the ancient sandy clay and sand deposits of the ancient Delta overlaid by the more recent Nile mud. At Raghama (kilometre 60) we meet



Left bank of the Nile opposite Eglit narth of Kom Ombo

with limestone in the valley of the Nile for the first time and immediately North of it the Gebel Silsila sandstone. The limestone near the river is of the cretaceous formation and the dark brown boulders of the lower Londinian formation. As far as I can learn, there is no limestone South of Gebel Silsila in the valley of the Nile right up to Lake Victoria, though Sir Samuel Baker informs me that there is kankar. south of Khartoum. South of Gebel Silsila, in the Nile deposits at a height of 11 metres above high flood, I found among heaps of common *orbiculas*, *unios* and *paludinæ*, numerous buffalo horns, hippopotamus teeth, elephant tusks, &c., which I have deposited in Professor Sickenberger's museum*. **(Gebel Silsila).**

It has been imagined that at some time the Gebel Silsila was a cataract of the Nile. Apparently it never was that, for the Nile deposits and oyster shells *(Ætheria Nilotica)* of the ancient river are met with North and South of the Silsila pass at exactly the same level, and no change is experienced until we reach Gebelain, where there is a decided drop in the level of the ancient deposits. The upturned and undermined hills which strew the Nile valley and Gebelain confirm the fact of its being the site of the great cataract of ancient days. Though the present channel of the Nile at Silsila is narrow and shallow, yet it is only a branch of the river ; the real channel 1500 metres wide and over 15 metres deep is on the right of the hill in which the quarries are, and is at present buried in mud and silt. The strata, moreover, at Silsila are all horizontal and there is no sign of undermining or overthrowing, as there certainly would be at the site of a cataract in stratified rock.

From Assûan northwards the sandstone is generally inferior to that South of the first cataract, while the belts of yellow clay increase in thickness and number until finally the sandstone gives place to the foliated marl which underlies the limestone. The low hill to the right of the Gebel Silsila pass is however an exception to this general rule and contains some good stone. It was an island formerly and resisted the action of the river when the weaker rocks on either side allowed the Nile to scour out a channel 1700 metres wide. Judging from the section at the southern quarry, I should say that the hill was either an ancient sand ridge or accumulation of sand behind some obstacle. It is considerably fissured but comparatively free from the belts of yellow clay which are met with as one descends below the level of the quarry bed at the island or everywhere else in the vicinity.

We have now passed out of the region of possible reservoirs and I shall hurry down the Nile until we reach the depression near the Fayoum.

(Gebelain). That part of the "Sin el Kidab" plateau which was cut through at Gebelain was only a promontory, and at Luxor the Nile again emerges into the low denuded plains on its right hand, having the plateau as a wall on its left. To the north of Kena, the plateau is entered

* Professor Schweinfurth considers these relics very interesting and Professor Sickenberger is sending them to Professor Dawson of London for identity.

for the second time and from, here to Cairo, the Nile keeps within it. At Kena the lower Londinian limestone dips below the level of the Nile deposit, and the upper Londinian formation monopolises the whole section of the limestone as far as a point midway between Assiout and Minia. Here the lower Parisian strata appear on the top of the plateau and the upper Londinian formation finally disappears at a little to the north of Minia. The lower Parisian formation is now met with as far as Cairo on the right bank ; on the left bank however the formation to the north of the Fayoum is upper Parisian with the exception of a small area near the Pyramids which is Senonian and Turonian. In the deserts east of Cairo we have also some lower Parisian stone.* (Kena). (Assiout). (Minia). (Cairo).

It is remarkable how each change of formation is accompanied by an intermediate layer of little consistency: the foliated marl between the upper cretaceous and the lower Londinian with the great denudations between Abu Simbel and Esna : the denudations to the east of Luxor and Kena when the lower and upper Londinian formations meet : the friable sandy strata to the left of Minia, where the upper Londinian gives place to the lower Parisian strata, and where the Nile valley is invaded with sand which has snatched a tract some 60 kilometres in length and 2 kilometres in width from the cultivated land and is travelling slowly onward: the great depressions of the Fayoum and the Wady Rayan where the upper and lower Parisian formations meet, and where to-day there are great hills of rolling sand. (Mean width of the Nile valley).

I think the mean width of the Nile valley as the river traverses the different formations is a fair gauge of the power of the different rocks to stand the action of the water. In granite the mean width is 500 metres ; in sandstone away from the granite it is 2000 metres ; in the upper Londinian formation it is 8000 metres ; in the lower Londinian formation it is 13000 metres and the upper Parisian 18000 metres. To the North of Wasta the valley contracts to 7000 metres because half the water of the ancient river found its way westwards into the ancient seas which covered the western deserts in those times.

The geological sections of the proposed channels for feeding the proposed Wady Rayan reservoir show clearly the enormous masses of salty and bitter marls, loams and clays, which were deposited in the ancient sea at the entrance to the Fayoum and Wady Rayan when the scouring action ceased and deposition followed. According to Dr. Schweinfurth, these formations are Pliocene.** The Parisian limestone (as well as these deposits) has an excess of salt. There are thick strata of salt everywhere in the vicinity of the Fayoum. (Wady Rayan).

* A Table at the end of this Appendix gives the typical fossils in Egypt of each of the above formations.

** " The Fayoum and Lake Mœris", by Major R. H. Brown — page 61-London 1892.

TYPICAL EGYPTIAN FOSSILS.

Upper Parisian.

Ostrea elegans.
Turitella Ægyptiaca.
Carolina placunoides.
Schizaster Mokatamensis.
Ostria Frasii.
Bones of Zeuglodon.

Lower Parisian.

The coral Eschera Schweinfurthii.
Vulsella legumen.
Echinolampas Frasii.
Lobacarcinus Paulino Wurtembergicus.
Nummulitus Gizehensis.
Teeth of Carcharodon.
Cerithium Kahirense.
Nautilus imperialis.

Upper Londinian.

Calianassa Nilotica.
Alveolina frumentiformis.
Cardium Ægyptiacum.
Cyprina Siutensis.
Sismondia Logotheti.

Lower Londinian.

Numulina gigantea.
Schizaster Navillei.
Hemispatangus pendulus.
Ostrea Kunusensis, (Mayer Eymar).
Cardium gigas.
Turritella angulata.
Cerithium Rapum.
Ostrea capriciosa.
Helix Isidis.
Ceritium Potiphar.
Nautilus Sowerbi.

Soissonian.

Rhynopygus Abundans, (Mayer Eymar).
Mytilus Woodi.
Cardita Wodehousii, (Mayer Eymar).
Turritella Nubica.
Natica Edmondi.
Cytheria lævigata.
Scalaria crispa.
Natica Alexandri.

Garumnian.

Ostrea Overwegi.

Danian.

Ostrea Janus.
Ostrea pterigota.
Ostrea velum.
Ostrea acutirostris.

APPENDIX VIII.

DETAILED ESTIMATES

OF THE COST OF THE RESERVOIR PROJECTS IN NUBIA.

INDEX

GENERAL ESTIMATES OF MASONRY.

A.

Estimate of quantities of masonry in the Solid dam: —

DEPTH OF WATER	CUBIC METRES OF MASONRY	DEPTH OF WATER	CUBIC METRES OF MASONRY	DEPTH OF WATER	CUBIC METRES OF MASONRY	DEPTH OF WATER	CUBIC METRES OF MASONRY	DEPTH OF WATER	CUBIC METRES OF MASONRY	DEPTH OF WATER	CUBIC METRES OF MASONRY
1	14.10	11	88.40	21	199.40	31	367.70	41	622.30	51	1007.00
2	20.30	12	97.40	22	213.30	32	388.70	42	654.00	52	1055.00
3	26.70	13	107.00	23	227.80	33	410.70	43	687.10	53	1105.00
4	33.40	14	117.00	24	242.90	34	433.50	44	721.60	54	1156.90
5	40.40	15	127.30	25	258.60	35	457.30	45	757.40	55	1210.80
6	47.60	16	138.10	26	274.90	36	482.10	46	794.70	..	..
7	55.20	17	149.30	27	292.00	37	508.00	47	833.70	..	..
8	63.00	18	161.10	28	309.90	38	534.90	48	874.40	..	..
9	71.20	19	173.30	29	328.40	39	562.90	49	916.90	..	..
10	79.60	20	186.10	30	347.70	40	592.00	50	961.00	..	..

B.

Estimate of quantities of foundation masonry below floor of undersluices under 22 metres head of water: —

Metres below sill............	1	Cubic metres of masonry........	20
» » »	2	» » »	40
» » »	3	» » »	60
» » »	4	» » »	81
» » »	5	» » »	102
» » »	6	» » »	124
» » »	7	» » »	146
» » »	8	» » »	168
» » »	9	» » »	191
» » »	10	» » »	214

C.

Estimates of quantities of masonry in 10 undersluices and one abutment pier or 57 metres in length of dam, when the sills are under 22 metres head of water : —

DESCRIPTION OF WORK.	N°	L	B	D	Q	Q
Granite Ashlar.						
Floors	10	19.4	3	.5	291.0	
Floor under grooves	20	2.0	1	.5	20.0	
Curtains	30	3	1	.5	45.0	
Sills	10	4	1.5	.5	30.0	
Vertical faces of sluices	20	15	.6	10.5	1890.0	
» » »	20	2.6	.6	1	31.2	
» » » at abutments	2	1	.3	6.5	7.8	
Lintels of sluices	10	7	3.5	.8	196.0	
» »	10	1.5	3.3	1.0	49.5	2561
Sandstone Ashlar.						
Upstream face wall	10	3.2	.6	12.5	240.0	
» faces of piers and grooves	20	5.2	.6	12.5	780.0	
» face above string course	1	57	1	2	114.0	
Downstream face above string course	1	62	.75	2	93.8	
Cornice and parapets	2	58	1.5	1	174.0	
Roadway	1	57	2.5	.3	42.8	
»	1	4.3	2	.3	2.6	
»	9	2.5	1.2	.3	8.1	
»	1	2.5	9	.3	6.8	1462
Rubble masonry.						
In piers	9	14	2.0	11	2772	
In abutment pier	1	14	9	11	1386	
» »	1	9	1	11	99	
Between lintels	9	9	2	.8	130	
» » at abutment pier	1	8	9	.8	58	
Body of dam	1	57	4.3	10.8	2647	
» »	1	57	3.0	1.8	308	
» » abutments	1	7.5	2	10.8	162	
» » »	1	5.2	2	1.8	19	7581

D.

Estimate of quantities of foundation masonry below floor of undersluices under 15 metres head of water: —

Metres below sill	1	Cubic metres of masonry	13.2
» » »	2	» » »	26.9
» » »	3	» » »	41.2
» » »	4	» » »	56.0
» » »	5	» » »	71.3
» » »	6	» » »	87.2
» » »	7	» » »	103.7
» » »	8	» » »	120.7
» » »	9	» » »	138.2
» » »	10	» » »	156.3

E.

Estimate of quantities of masonry in 10 undersluices and one abutment pier or 57 metres in length of dam, when the sills are under 15 metres of water: —

DESCRIPTION OF WORK.	N°	L	B	D	Q	Q
Granite Ashlar.						
Floor	10	14.5	3.0	.5	217.5	
Floor under grooves	20	2	1	.5	20.0	
Curtains	30	3	1	.5	45.0	
Sils	10	4	1.5	.5	30.0	
Vertical faces of sluices	20	10	.6	10.5	1296.0	
» » »	20	2.4	.6	1	28.8	
» » »	2	2	.6	5	12.0	
Lintels of sluices	10	4.5	3.5	.8	126.0	
» »	10	7	1.4	1	42.0	1818
Sandstone Ashlar.						
Upstream face walls	10	3	.6	5	90	
Piers and grooves up to roadway	20	5.4	.6	5	324	
Piers and grooves above roadway	20	5.4	.6	8	519	
Downstream face wall below roadway	1	60	.8	2	96	
Roadway	1	57	2.7	.3	46	
»	1	7.5	.7	.3	2	
Upper face walls, mouldings and cornices.	2	57	1	2.5	285	1302
Rubble masonry.						
Piers	9	9	2	11.3	1831	
Abutment	1	9	9	11.3	916	
»	1	1.5	9	11.3	153	
Body of dam	1	57	4	5	1140	
» abutment	1	9	.7	5	32	
Piers	9	3	1	8	216	
Abutment	1	9	4	8	288	4576

Estimate of the cost of the Silsila dam to hold up water to R. L. 100.00.

Rock excavation. —	Right flank...............	550 × 48 × 16 =	422,400 cubic metres
	Left flank................	600 × 75 × 16 =	720,000 »
	Floor of dam.............	560 × 50 × 2 =	56,000 »
	Excavation of locks.......	200 × 18 × 20 =	72,000 »
	» »	200 × 35 × 10 =	70,000 »
	Lock channel.............	1600 × 25 × 18 =	720,000 »
			2,060,400 cubic metres

Rubble masonry in foundation. —	(B) Main part of dam	400 × 102 =	40,800 cubic metres
	Upstream apron...............	400 × 3 × 4 =	4,800 »
	Downstream apron.........	400 × 3.5 × 20 =	28,000 »
	» »	400 × 2 × 10 =	8,000 »
	» »	400 × 3 × 2 =	2,400 »
	» »	160 × 37 × 2 =	11,840 »
			95,840 cubic metres

UNDERSLUICES.

80 undersluices under 22 metres head of water (C).
30 » under 15 » » » (E).

Granite Ashlar......................	8 × 2561 =	20,488	
	3 × 1818 =	5,454 =	25,912 cubic metres
Sandstone Ashlar..................	8 × 1462 =	11,696	
	3 × 1362 =	4,086 =	15,782 cubic metres
Rubble masonry.....................	8 × 7581 =	60,648	
	3 × 4576 =	13,728 =	74,376 cubic metres

Regulating apparatus 110 × 10 × 2 = 2200 square metres.

LOCKS.

Granite Ashlar. —	Upper lock gate	32 × 20 × 2 =	1,280	
	Middle »	25 × 20 × 2 =	1,000	
	End »	22 × 20 × 2 =	880	
			3,160	
		Add.............	3,160 =	6,320 cubic metres

Lock gates......	2 × 16 × 12 =	384	
	1 × 13 × 12 =	156	
		540	
	Add	540 =	1,080 square metres

Earthen bank across right channel..... 1400 × 62 × 6 = 520,800 cubic metres

Abstract of cost. —

Rock excavation............	2,060,400 cubic metres	at L.E. .07	= L.E.	144,228
Rubble masonry in foundation	95,840 »	» » 1.50	= »	143,760
Granite Ashlar in undersluices	25,942 »	» » 5.00	= »	129,710
Sandstone » »	15,782 »	» » 2.50	= »	39,455
Rubble Masonry. »	74,376 »	» » 1.00	= »	74,376
Regulating apparatus........	2,200 square metres	» » 75.00	= »	165,000
Coffer dams and pumping.....	....		»	100,000
Granite Ashlar in locks.......	6,320 cubic metres	» » 5.00	= »	31,600
Lock gates..................	1,080 square metres	» » 30.00	= »	32,400
Earthwork in dam...........	520,800 cubic metres	» » .04	= »	20,832
			TOTAL... L.E.	881,361
			Contingencies at 10 % »	88,136
			Cost of dam, &c. — GRAND TOTAL... L.E.	969,497

Compensation for land, villages, etc., drowned out: —

Assuân..............................	L.E.	300,000	
Lands..............................	»	200,186	
Villages............................	»	45,500	
Date trees	»	11,100	
Islands............................	»	10,527	
	L.E.	567,321	
Contingencies at 10 %	»	56,732	L.E. 624,053

GRAND TOTAL.... L.E. 1,593,550

Or say L.E. 1,594,000

Estimate of the cost of the Silsila dam to hold up water to R. L. 104.00.

Rock excavation. — Right flank	550 × 48 × 12 =	316,800	cubic metres
Left flank	600 × 75 × 12 =	540,000	»
Floor of dam	560 × 50 × 2 =	56,000	»
Excavation of locks	200 × 18 × 20 =	72,000	»
» »	200 × 35 × 10 =	70,000	»
Lock channel	1600 × 25 × 17 =	680,000	»
		1,734,800	cubic metres

Rubble masonry in foundation.—(B) Main part of dam	400 × 214 =	85,600	cubic metres
Upstream apron	400 × 3 × 10 =	12,000	»
Downstream apron	400 × 20 × 6.5 =	52,000	»
» »	400 × 10 × 2 =	8,000	»
» »	400 × 3 × 2 =	2,400	»
» »	160 × 37 × 2 =	11,840	»
		171,840	cubic metres

UNDERSLUICES.

85 Undersluices under 22 metres head of water (C).
30 » under 15 » » » (E).

Granite Ashlar (*)	8 × 2561 = 20,488		
	3 × 1818 = 5,454	25,942	cubic metres
Sandstone Ashlar	8 × 1462 = 11,696		
	3 × 1362 = 4,086	15,782	cubic metres
Rubble masonry	8 × 7581 = 60,648		
	3 × 4576 = 13,728	74,376	cubic metres

Regulating apparatus .... 115 × 10 × 2 = 2,300 square metres.

LOCKS.

Granite Ashlar	same as low level dam =	6,320	cubic metres
Lock gates	2 × 17 × 12 = 408		
	1 × 14 × 12 = 168 576		
	Add .... 576 =	1,152	square metres

EARTHEN BANK across right channel: —

Earthwork	1500 × 90 × 10 =	1,350,000	cubic metres
Pitching slopes	1500 × 15 × 1 =	22,500	cubic metres

(*) The Ashlar here will be slightly in excess and the rubble masonry will be less, but the total cost will not be appreciably altered.

Regulator on weir : —

Rubble masonry.. — Floor...... $300 \times 25 \times \frac{5}{2} = 18{,}750$

Piers... $54 \times 8 \times \frac{15}{2} \times \frac{3}{2} = 4{,}860$ — 23,610 cubic metres

Sandstone Ashlar. — Floor...... $360 \times 25 \times \frac{1}{2} = 4{,}500$

Piers... $54 \times 4 \times \frac{15}{2} \times \frac{3}{2} = 2{,}430$ — 6,930 cubic metres

Regulating apparatus................	55 × 5 × 7 =	1,925 square metres
Rock cutting..........................	200 × 60 × 15 =	18,000 cubic metres
Grouting part of top course of weir....	300 × 100 =	30,000 square metres
Masonry core in stone weir............	300 × 10 × 3 =	9,000 cubic metres

Abstract of cost : —

Rock excavation............	1,734,800 cubic metres	at L.E. .07 =	L.E.	121,436
Rubble masonry in foundation	171,840 »	» » 1.50 =	»	257,760
Granite Ashlar in undersluices	25,942 »	» » 5.00 =	»	129,710
Sandstone » » »	15,782 »	» » 2.50 =	»	39,455
Rubble masonry »	74,376 »	» » 1.00 =	»	74,376
Regulating gates.............	2,300 square metres	» » 75.00 =	»	172,500
Cofferdam and pumping......			»	100,000
Granite Ashlar in locks......	6,320 cubic metres	» » 5.00 =	»	31,600
Lock gates..................	1,152 square metres	» » 30.00 =	»	34,560
Earthwork in bank.........	1,350,000 cubic metres	» » .04 =	»	54,000
Pitching on bank............	22,500 »	» » .10 =	»	2,250
		Total...	L.E.	1,017,647
		Contingencies at 10 %	»	101,764
		Grand Total...	L.E.	1,119,411

Regulator on weir : —

Rubble masonry......	23,610 at L.E. 1.5 =	L.E. 35,415			
Sandstone Ashlar.....	6,930 » » 3 =	» 20,790			
Regulating apparatus.	1,925 » » 4 =	» 7,700			
Rock cutting.........	18,000 » » .07 =	» 1,260			
Grouting.............	30,000 » » .50 =	» 15,000			
Masonry core.........	9,000 » » 1.5 =	» 13,500			
	Total...	L.E. 93,665			
	Contingencies at 10 %	» 9,366		L.E.	103,031
		Grand Total cost of works..		L.E.	1,222,442

Compensation. — As for low level dam............	L.E. 624,053			
Date trees......................	» 26,000			
Land..........................	» 14,000			
Villages.......................	» 5,000		L.E.	669,053
		Grand Total...	L.E.	1,891,495

Or say L.E. 1,890,000

Estimate of the cost of the Assuân dam to hold up water to R. L. 106.00

Rubble masonry in solid dam (**A**).

DISTANCE FROM LEFT	HEAD OF WATER	AREA OF SECTION	Q	Q
0	0	0		
20	4	33.4		
40	6	47.6		
60	6	47.6		
75	10	79.6	3,113	
125	23	227.8		
140	23	227.8		
160	23	227.8		
180	23	227.8		
200	16	138.1		
215	16	138.1	18,000	
280	16	138.1		
300	16	138.1		
320	20	186.1	5,800	
380	18	161.1		
400	15	127.3		
410	15	127.3	4,080	
Abutment	48 × 35 × 15	25,200	25,200	
490	20	186.1		
500	14	97.4		
520	12	117.0		
540	13	107.0	6,000	
900	19	173.3		
920	16	138.1		
940	16	138.1		
960	15	127.3		
980	6	47.6		
1000	4	33.4	11,082	
Abutment	50 × 35 × 4	7,000	7,000	
1020	7	55.2		
1040	8	63.0		
1060	9	71.2		
1080	8	63.0		
1100	9	71.2		
1120	9	71.2		
1140	8	63.0		
1160	10	79.6		
1180	10	79.6		
1200	12	97.4	14,088	
Carried forward.	....	....	94,363	

Estimate of the cost of the Assuân dam to hold up water to R. L. 106.60. [Continued]

Rubble masonry in solid dam (**A**). [Continued].

DISTANCE FROM LEFT	HEAD OF WATER	AREA OF SECTION	Q	Q
Brought forward.	..	..	94,363	
1220	12	97.4		
1240	11	88.4		
1260	13	107.0		
1280	10	79.6		
1300	10	79.6		
1320	7	55.2		
1340	6	47.6		
1360	8	63.0		
1380	9	71.2		
1400	10	79.6	15,372	
1420	16	138.1		
1440	19	173.3		
1460	11	88.4		
1480	3	26.7		
1500	0	0	8,530	
CLOSING LOCK CHANNEL				
0	9	71.2		
20	19	173.3		
40	16	138.1		
60	0	0	6,940	
LEFT CHANNEL				
0	2	20.3		
20	7	55.2		
40	11	88.4		
60	15	127.3		
80	17	149.3		
100	15	127.3		
120	17	149.3		
140	12	97.4	16,290	
160	11	88.4		
180	12	97.4		
200	13	107.0		
220	15	127.3		
240	12	97.4		
260	12	97.4		
280	17	149.3		
300	0	0	15,284	
TOTAL RUBBLE MASONRY IN SOLID WEIRS.....................				156,779 cubic metres

Rock excavation for lock......	450 × 22 × 15 = 148,500	
	Add......... 148,500	
	Total................	297,000 cubic metres
Rubble masonry in lock........	150 × 15 × 7 = 15,750	
	Add 15,750	
	Total	31,500 cubic metres

UNDERSLUICES.

70 undersluices under 15 metres head of water (E).
30 » under 22 metres » » (C).

Granite Ashlar......................	7 × 1818 = 12,726	
	3 × 2561 = 7,683	20,409 cubic metres
Sandstone Ashlar....................	7 × 1362 = 9,534	
	3 × 1462 = 4,386	13,920 cubic metres
Rubble masonry.....................	7 × 4576 = 32,032	
	3 × 7581 = 22,743	54,775 cubic metres
Regulating apparatus	100 × 10 × 2 = 2,000	2,000 square metres
Lock gates..................	2 × 15 × 12 = 360	
	1 × 12 × 12 = 144 504	
	Add................ 504	1,008 square metres

Abstract of cost : —

Rubble masonry in solid dam	156,779 cubic metres	at L.E.	.80 =	L. E. 125,423
Rock excavation for lock....	297,000 »	» »	.08 =	» 23,760
Rubble masonry in lock.....	31,500 »	» »	1.00 =	» 31,500
Ashlar work » »				» 5,000
Lock gates................	1,008 square metres	» »	30.00 =	» 30,240
Granite Ashlar in dam.....	20,409 cubic metres	» »	5.00 =	» 112,045
Sandstone Ashlar in dam....	13,920 »	» »	2.50 =	» 34,800
Rubble masonry in dam....	54,775 »	» »	1.00 =	» 54,775
Regulating apparatus.......	2,000 square metres	» »	75.00 =	» 150,000
Clearing foundation, &c...				» 10,000
Coffer dam and pumping...				» 30,000
			TOTAL...	L. E. 597,543
			Contingencies at 10 %...	» 59,754
			GRAND TOTAL FOR WORKS...	L. E. 657,297

Compensation for land and villages drowned : —

Land......................	L. E. 16,476		
Date trees.................	» 57,334		
Village....................	» 28,616		
Islands....................	» 1,520	L.E. 103,946	
Contingencies at 10 %...	»	10,394	L.E. 114,340

GRAND TOTAL... L.E. 771,637

Say L.E. 772,000

Estimate of the cost of the Kalabsha Reservoir dam to hold up water to R. L. 118.00.

Rubble masonry in solid section (**A**).

DISTANCE FROM LEFT	HEAD OF WATER	AREA OF SECTION	Q
1020	4	33.4	
1000	7	55.2	
980	7	55.2	
960	6	47.6	
940	2	20.3	
920	2	20.3	
900	12	97.4	
880	12	97.4	
860	0	0	8,200
825	8	63.0	
815	8	63.0	630
740	33	410.7	
720	42	654.0	
700	44	721.6	
680	44	721.6	
660	43	687.1	
640	40	592.0	
620	40	592.0	77,560
		Add for contingencies in depth.....	15,000
		TOTAL SOLID DAM...	101,390

Rubble masonry in foundation of open dam.

FROM RIGHT TO LEFT	LENGTH	DEPTH BELOW SILL		
(**B**) Low level sill	40	$\frac{0+10}{2}$	107	4,280
(**B**) » » »	30	$\frac{0+10}{2}$	107	3,510
(**D**) High » »	30	$\frac{0+10}{2}$	78	2,340
(**B**) Low » »	40	$\frac{0+10}{2}$	107	4,280
(**D**) High » »	20	$\frac{0+5}{2}$	36	720
(**B**) Low » »	100	$\frac{5+10}{2}$	158	25,280
			TOTAL....	40,410

UNDERSLUICES.

80 Undersluices under 22 metres head of water (C).
40 » under 15 metres » » (E).

Granite Ashlar.................... 8 × 2561 = 20,488
4 × 1818 = 7,272 = 27,760 cubic metres

Sandstone Ashlar................ 8 × 1462 = 11,696
4 × 1362 = 5,448 = 17,144 cubic metres

Rubble masonry .... 8 × 7581 = 60,648
4 × 4576 = 18,304 = 78,952 cubic metres

Regulating apparatus........ 120 × 10 × 2 = 2,400 = 2,400 square metres

Lock gates. — Upper .... 18 × 12 = 216
Middle......... 6 × 12 = 72
Lower......... 16 × 12 = 192 = 480
Add.............................. 480 = 960 square metres

LOCKS.

Granite Ashlar as for Silsila.......................... 6,320 cubic metres

Rubble masonry... 2 × 150 × 12 × 6 = 21,600
3 × 20 × 15 × 5 = 4,500
1 × 45 × 15 × 6 = 4,050 = 30,150
Add............... 30,150 = 60,300 cubic metres

Rock cutting. — Lock channel... 600 × 25 × 7 = 105,000
Add.............. 105,000 = 210,000 cubic metres

Abstract of cost : —

Rubble masonry in solid dam	101,390	cubic metres	at	L. E. 1.50 =	L.E.	152,085
Rubble masonry in foundation	40,410	»	»	» 1.50 =	»	60,615
Granite Ashlar in undersluices	27,760	»	»	» 5.00 =	»	138,800
Sandstone Ashlar »	17,144	»	»	» 2.50 =	»	42,860
Rubble masonry »	78,952	»	»	» 1.00 =	»	78,952
Regulating gates.............	2,400	square metres	»	» 75.00 =	»	180,000
Lock gates	960	»	»	» 30.00 =	»	28,800
Granite Ashlar for locks......	6,320	cubic metres	»	» 5.00 =	»	31,600
Rubble masonry for locks.....	60,300	»	»	» 1.00 =	»	60,300
Rock cutting................	210,000	»	»	» .08 =	»	16,800
Clearing foundation..........................					»	10,000
Cofferdams and pumping..........................					»	250,000

TOTAL.... L.E. 1,050,812
Contingencies at 10 %..... » 105,081

GRAND TOTAL FOR WORKS.... L.E. 1,155,893

Compensation for land, etc., drawned out : —

Date trees.............................. L.E. 225,000
Villages................................ » 83,000
Lands.................................. » 85,000

L.E. 393,000
Contingencies at 10 % » 39,300 L.E. 432,300

GRAND TOTAL.... L.E. 1,588,193

Or say L.E. 1,589,000

Abstract of cost of a Reservoir dam at Kalabsha to hold up water to R.L. 115.00.

Rubble masonry in solid dam.	85,000	cubic metres	at	L.E.	1.5	=	L.E.	127,500
Rubble masonry in foundation	25,000	»	»	»	1.5	=	»	37,500
Granite Ashlar in underluices.	25,942	»	»	»	5.0	=	»	129,710
Sands one Ashlar »	15,782	»	»	»	2.5	=	»	39,455
Rubble masonry »	74,376	»	»	»	1.0	=	»	74,376
Regulating gates............	2,200	square metres	»	»	75.0	=	»	165,000
Lock gates....................	860	»	»	»	30.0	=	»	25,800
Granite Ashlar for locks.......	6,320	cubic metres	»	»	5.0	=	»	31,600
Ruble masonry for locks......	45,000	»	»	»	1.0	=	»	45,000
Rock cutting.................	210,000	»	»	»	0.08	=	»	16,800
Clearing foundation..							»	10,000
Cofferdams and pumping..							»	250,000
						Total........	L.E.	952,741
						Contingencies.	»	95,274
						Grand Total for works.....	L.E.	1,048,015

Compensation for land, &c. : —

Date trees................................	L.E. 116,800		
Land....................................	» 56,000		
Villages.................................	» 45,000		
	L.E. 217,800		
Contingencies at 10 %	» 21,780	L.E.	239,580

Grand Total L.E. 1,287,595

Or L.E. 1,288,000

Estimate of the cost of Philæ dam to hold up water to R. L. 118.00.

Solid dam, Rubble masonry.

DISTANCE FROM LEFT	DEPTH OF WATER	AREA OF SECTION	Q
150	0	0	
175	32	389	
200	33	411	
225	36	483	
250	39	563	
275	43	688	
300	44	722	
325	46	795	
350	47	834	
375	47	834	
400	45	758	
425	48	875	
450	48	875	
475	48	875	
500	47	834	
525	44	722	
550	43	688	
575	43	688	
600	28	310	
625	6	48	
650	0	0	319,800 cubic metres

*Foundation of open dam below undersluices (**B** and **D**).*

(B) Left channel..................... 230 × 102 = 23,460
(B) Right channel.................. 50 × 146 = 7,300
(D) » » .... 80 × 104 = 8.320 39,080 cubic metre

UNDERSLUICES.

Granite Ashlar, Sandstone Ashlar, Rubble masonry and gates the same as Kalabsha for holding up water to R. L. 118,00.

Rock Excavation. — Left channel....... 200 × 35 × 7 = 49,000 cubic metres
» » .... 200 × 45 × 5 = 45,000 »
Right » .... 200 × 25 × 5 = 25,000 »
Lock » ...2 × 400 × 25 × 20 = 400,000 »

519,000 cubic metres

Masonry for lock (nil). —

Granite Ashlar for lock (same as Kalabsha).

Lock gate area same as Kalabsha.

Abstract of cost of dam: —

Rubble masonry in dam..............	319,800	cubic metres	at L.E.	1.50	=	L.E.	479,700
» » in foundation........	39,080	»	» »	1.50	=	»	58,020
Granite Ashlar in undersluices........	27,760	»	» »	5.00	=	»	138,800
Sandstone Ashlar »	17,144	»	» »	2.50	=	»	42,860
Rubble masonry »	78,952	»	» »	1.00	=	»	78,952
Regulating gates....................	2,400	square metres	» »	75.00	=	»	180,000
Lock gates...........................	960	»	» »	30.00	=	»	28,800
Granite Ashlar for locks..............	6,320	cubic metres	» »	5.00	=	»	31,600
Rock cutting.........................	519,000	»	» »	.08	=	»	41,520
Clearing foundation...						»	30,000
Coffer dam and pumping...						»	300,000
					Total......	L.E.	1,410,852
			Contingencies at 10 %......			»	141,085
			Grand Total for works....			L.E.	1,551,937

Compensation. —

As at Kalabsha..............................	L.E. 393,000		
Land..	» 18,000		
Dates.......................................	» 57,500		
Villages....................................	» 28,709		
	L.E. 497,200		
Contingencies at %	» 49,720	L.E.	546,920
Grand Total.....		L.E.	2,098,857

Or say L.E. 2,100,000

ASSUAN CATARACT DAM.

Abstract of the cost of the Assuân Cataract dam to hold up water to R. L. 115.00.

Rubble masonry in solid dam.	344,638	cubic metres	at	L.E.	.8	=	L E.	275,710
Rock excavation for lock.....	297,000	»	»	»	.08	=	»	23,760
Rubble masonry in lock......	63,000	»	»	»	1.	=	»	63,000
Ashlar work...							»	5,000
Lock gates.................	1,200	squares metres	»	»	30.	=	»	36,000
Granite Ashlar..............	28,503	cubic metre	»	»	5.	=	»	142,515
Sandstone Ashlar............	17,244	»	»	»	2.5	=	»	43,110
Rubble masonry in dam......	82,057	»	»	»	1.	=	»	82,057
Regulating apparatus........	2,400	»	»	»	75.	=	»	180,000
Clearing foundation...							»	50,000
Cofferdams and pumping...							»	30,000
							L.E.	931,152
			Contingencies 10 %.......				»	93,115
							L.E.	1.024,267
			Compensation + 10 %.....				»	346,000
							L.E.	1,370,267

timate of the cost of the Assuân dam to hold up watsr to R. L. 115.00.

Rubble masonry in Solid dam.

DISTANCE FROM RIGHT	HEAD OF WATER	AREA OF SECTION	QUANTITIES	QUANTITIES
Main dam.				
0	..	..		
20	2	20.30		
40	7	55.20		
60	10	79.60		
80	11	88.40		
100	19	173.30		
120	28	309.90		
140	23	227.80		
160	18	161.10		
180	18	161.10		
200	17	149.30		
220	12	97.40		
240	15	127.30		
260	18	161.10		
280	17	149.30		
300	21	199.42		
320	20	186.10	26,932	
30 Sluices.				
500	18	161.10		
520	17	149 30	4,200	
Abutment............	42 × 12.00 × 35 =		17,640	
580	14	117.00		
600	18	161.10		
620	24	242.90		
640	24	242.90		
660	26	274.90	20,776	
60 Sluices.				
1000	20	186.10		
1020	22	213.30		
1040	23	227.80		
1060	21	199.40		
1080	30	347.70		
1100	24	242.90	28,344	
ıtment...............	43 × 22.00 × 35 =		33,110	
1040	22	213.30		
1060	25	258.60		
1080	28	309.90		
1200	29	328.40		
1220	27	292.00		
1240	29	328.40		
1260	26	274.90		
1280	24	242.90		
1300	23	227.80		
1320	26	274.90		
1340	25	258.60		
1360	25	258.60		
1380	29	328.40		
1400	28	309.90		
1420	28	309.90		
1440	29	328.40		
1460	29	328.40	97,466	
Abutment............	43 × 20.00 × 35 =		30,100	
1520	14	117.00		
1540	12	97.40		
1560	8	63.00		
1580	..	..	5,548	
		IN SOLID WALL.............		264,116 cubic metres

Estimate of the cost of the Assuân dam to hold up water to R. L. 115.0(
[Continued].

Rubble masonry in solid dam.

DISTANCE FROM LEFT	HEAD OF WATER	AREA OF SECTION	QUANTITIES	QUANTITIES
Left channel.				
0	...	...		
10	2	20 30		
20	4	33.40		
30	10	79.60		
40	12	97.40		
50	15	127.30		
60	17	149.30		
70	18	161.10		
80	20	186.10		
90	21	199.40		
100	25	258.60		
110	26	274.90	31,745	
30 Sluices.				
280	20	186.10		
290	20	186.10		
300	24	242.90		
310	25	258.60		
320	24	242.90		
330	5	40.40		
340	1	14.10	23,422	55,170 cubic metres
Lock channel.				
0	...	...		
10	5	40.40		
20	7	55.20		
30	16	138.10		
40	22	213.30		
50	24	242.90		
2 Sluices.				
60	24	242.90		
70	23	227 80		
80	13	107.00	25,352	25,352 cubic metres

SUMMARY.

Main Dam..............................	264,116
Left Channel............................	55,170
Lock Channel...........................	25,352
Cubic metres...	344,638

ASSUAN DAM.

bstract of the cost of the Assuân dam to hold up water to R. L. 118.00.

Rubble masonry in solid dam..	442,105	cubic metres	at	L.E.	.8	=	L.E.	353,684
Rock excavation for lock......	297,000	»	»	»	.08	=	»	23,760
Rubble masonry in lock.......	189,000	»	»	»	1.	=	»	189,000
Ashlar work........................							»	5,000
Lock gates..................	1,200	square metres	»	»	30.	=	»	36,000
Granite ashlar................	28,503	cubic metres	»	»	5.	=	»	142,515
Sandstone ashlar.............	17,244	»	»	»	2.5	=	»	43,110
Rubble masonry under sluice..	40,000	»	»	»	1.5	=	»	60,000
Rubble masonry in dam.......	82,057	»	»	»	1.	=	»	82,057
Regulating apparatus.........	2,400	square metres	»	»	75.	=	»	180,000
Clearing foundation							»	50,000
Cofferdams and pumping							»	30,000
							L,E.	1,195,126
			Contingencies 10 %.......				»	119,512
							L.E.	1,314,638
			Compensation + 10 %.....				»	346,000
							L.E.	1,660,638

Estimate of the cost of the Assuân dam to hold up water to R.L. 118.00

Rubble masonry in Solid dam.

DISTANCE FROM RIGHT	HEAD OF WATER	AREA OF SECTION	QUANTITIES	QUANTITIES
Main dam.				
0	0	0		
20	5	40.40		
40	9	71.20		
60	13	107.00		
80	14	117.00		
100	22	213.30		
120	31	367.70		
140	26	274.90		
160	21	199.40		
180	21	199.40	31,806	
200	20	186.10		
220	15	127.30		
240	18	161.10		
260	21	199.40		
280	20	186.10		
300	24	242.90		
320	23	227.80		
34 Sluices.				
500	21	199.40		
520	20	186.10	34,326	
Abutments............	42 × 35.00 × 15 =		22,050	
580	17	149.30		
600	21	199.40		
620	27	292.00		
640	27	292.00		
660	29	328.40	25,222	
60 Sluices.				
1000	23	227.80		
1020	25	258.60		
1040	26	274.90		
1060	24	242.90	20,104	
1080	33	410.70		
1100	27	292.00	14,054	
Abutments............	43 × 25.00 × 35 =		36,750	
1140	25	258.60		
1160	28	309.90		
1180	31	367.70		
1200	32	388.70		
1220	30	347.70		
1240	32	388.70		
1260	29	328.40		
1280	27	292.00	53,634	
1300	26	274.90		
1320	29	328.40		
1340	28	309.90		
1360	28	309.90		
1380	32	388.70		
1400	31	367.70		
1420	31	367.70		
1440	32	388.70		
1460	32	388.70	62,492	
Abutments............	43 × 23.00 × 35 =		34,615	
1520	17	149.30		
1540	15	127.30		
1560	11	88.40		
1580	0	0	7,300	
	In solid wall................			342,353 cubic metres.

Estimate of the cost of the Assuân dam to hold up water to R. L. 118.00 [Continued].

Rubble masonry in Solid dam.

DISTANCE IN RIGHT	HEAD OF WATER	AREA OF SECTION	QUANTITIES CUBIC METRES	QUANTITIES CUBIC METRES
Left channel from left.				
0	...	...		
10	5	40.40		
20	7	55.20		
30	13	107.00		
40	15	127.30		
50	18	161.10		
60	20	186.10		
70	21	199.40		
80	23	227.80		
90	24	242.90		
100	28	309.90		
110	29	328.40	39,710	
30 Sluices.				
280	23	227.80		
290	23	227.80		
300	27	292.00		
310	28	309.90		
320	27	292.00		
330	8	63.40		
340	4	33.40	28,926	68,636 in Left channel
Lock channel.				
0	...	...		
10	8	63.00		
20	10	79.60		
30	19	173.30		
40	24	242.90		
2 Sluices.				
50	27	292.00		
60	27	292.00		
70	26	274.90		
80	15	138.10	31,116	31,116 in Lock channel
Masonry under sluices..	650 × 20 × 3 = 39,000			

SUMMARY.

Solid Dam............................	342,353
Left channel..........................	68,636
Lock channel..........................	31,116
Total in cubic metres...	442,105

APPENDIX IX.

CONTENTS OF RESERVOIRS IN NUBIA.

APPENDIX IX.

CONTENTS OF RESERVOIRS IN NUBIA.

Contents of the low level Reservoir at Silsila.

KILOMETRE	AREA R. L. 87 To R. L. 100	KILOMETRE	AREA R. L. 87 To R. L. 100	KILOMETRE	AREA R. L. 87 To R. L. 100	KILOMETRE	AREA R. L. 87 To R. L. 100	KILOMETRE	AREA R. L. 87 To R. L. 100
0	8866		1,669,504		2,260,642		2,434,139		2,532,818
1	39350	41	15117	81	4740	121	2875	161	2253
2	81747	42	28287	82	5686	122	2875	162	1915
3	93685	43	26380	83	5266	123	2875	163	2077
4	34816	44	20087	84	7184	124	2875	164	1871
5	43383	45	27990	85	5502	125	2442	165	1699
6	44855	46	35619	86	3997	126	2163	166	1856
7	38593	47	17999	87	3854	127	2204	167	1593
8	49152	48	18334	88	6135	128	2352	168	1864
9	47893	49	21755	89	4015	129	2701	169	1035
10	49550	50	18203	90	4981	130	2651	170	1568
11	53050	51	12813	91	3784	131	3261	171	1424
12	59384	52	21189	92	2865	132	2931	172	1403
13	41427	53	23476	93	5739	133	2548	173	1228
14	47055	54	22351	94	4329	134	1742	174	1264
15	35799	55	15454	95	4259	135	2210	175	904
16	21494	56	17438	96	4593	136	2531	176	865
17	19126	57	23054	97	4289	137	2648	177	604
18	30030	58	16336	98	4663	138	2727	178	895
19	40416	59	22613	99	5799	139	2666	179	886
20	69250	60	27105	100	5310	140	1947	180	1004
21	61015	61	12931	101	4828	141	1772	181	1031
22	72967	62	12931	102	4562	142	1887	182	962
23	77523	63	12931	103	4350	143	2075	183	864
24	68038	64	12931	104	3803	144	1840	184	606
25	64239	65	12931	105	3910	145	2098	185	358
26	49094	66	12931	106	3827	146	2115	186	331
27	55319	67	17700	107	3548	147	2324	187	292
28	34369	68	2590	108	3497	148	2280	188	494
29	29064	69	5650	109	4237	149	2113	189	521
30	34019	70	6437	110	4885	150	2239	190	340
31	35740	71	4613	111	4610	151	1910	191	254
32	23476	72	4972	112	4447	152	1814	192	209
33	17858	73	4392	113	5026	153	2185	193	140
34	15528	74	4219	114	4856	154	2576	194	84
35	13318	75	5651	115	1048	155	2836	..	..
36	9383	76	6487	116	2215	156	3122	..	..
37	10367	77	4234	117	3098	157	3139	..	..
38	11044	78	5787	118	3423	158	2925	..	..
39	15739	79	4647	119	2902	159	3289	..	..
40	22483	80	4570	120	3400	160	2916	..	..
	1,669,504		2,260,642		2,434,139		2,532,818		2,567,512

Reservoir to R. L. 100 — 2,568,000,000 cubic metres.

Contents of the high level Reservoir at Silsila.

KILOMETRE	AREA R. L. 90 To R. L. 104	KILOMETRE	AREA R. L. 90 To R. L. 104	KILOMETRE	AREA R. L. 90 To R. L. 104	KILOMETRE	AREA R. L. 90 To R. L. 104	KILOMETRE	AREA R. L. 90 To R. L. 104
0	12704		2,713,981		3,269,304		3,528,706		3,718,552
1	30938	51	16307	101	7780	151	3754	201	1834
2	96028	52	25835	102	7300	152	3825	202	1754
3	55180	53	27673	103	6991	153	4530	203	1732
4	54542	54	27793	104	6480	154	5398	204	1868
5	75136	55	20212	105	6745	155	5804	205	1822
6	74591	56	16056	106	6331	156	6346	206	2014
7	64153	57	22209	107	5913	157	6477	207	1882
8	89581	58	13471	108	5837	158	6224	208	1441
9	94680	59	18708	109	7062	159	8257	209	1284
10	80288	60	22958	110	8113	160	5913	210	1098
11	92362	61	11554	111	7580	161	6911	211	1322
12	103421	62	11554	112	7475	162	4380	212	1291
13	85326	63	11554	113	8520	163	4741	213	1375
14	88685	64	11554	114	8634	164	4317	214	1469
15	46743	65	11554	115	1718	165	3951	215	1633
16	55503	66	11554	116	3705	166	4595	216	1442
17	40046	67	24573	117	5020	167	4035	217	1273
18	95905	68	4716	118	5669	168	4713	218	1384
19	68203	69	8340	119	4842	169	3630	219	1201
20	99440	70	9653	120	6510	170	4141	220	1061
21	86171	71	6923	121	4835	171	3963	221	1037
22	100325	72	7152	122	48[illegible]5	172	3917	222	1222
23	109507	73	6368	123	4835	173	3500	223	1157
24	99178	74	6129	124	4835	174	3914	224	1241
25	88193	75	8259	125	3976	175	3102	225	1362
26	67337	76	9747	126	3737	176	2885	226	1429
27	80053	77	6260	127	3774	177	2169	227	1344
28	54953	78	8637	128	4052	178	3228	228	1302
29	44223	79	6987	129	4888	179	3214	229	1501
30	45017	80	7040	130	5341	180	3909	230	1072
31	44696	81	7110	131	5387	181	4031	231	1018
32	25652	82	8606	132	5044	182	3983	232	1112
33	18607	83	8426	133	4584	183	3745	233	1332
34	15325	84	11084	134	4385	184	2843	234	1191
35	14535	85	8448	135	4[illegible]95	185	2219	235	973
36	7915	86	6302	136	4824	186	2549	236	1097
37	10412	87	6321	137	4766	187	3972	237	800
38	11208	88	9194	138	4959	188	4524	238	653
39	16182	89	6143	139	4900	189	3756	239	538
40	26847	90	7547	140	3578	190	2821	240	872
41	16432	91	6012	141	3340	191	2482	241	245
42	19054	92	5249	142	3595	192	2392	242	545
43	29510	93	9159	143	3872	193	2213	243	500
44	20572	94	7431	144	3484	194	1919	244	483
45	38230	95	7185	145	3877	195	2035	245	327
46	42221	96	7483	146	4008	196	1963	246	327
47	20561	97	6769	147	4107	197	1824	247	135
48	19593	98	7721	148	4406	198	1743	248	183
49	22755	99	9101	149	4185	199	1928	249	180
50	14751	100	8702	150	4473	200	2061	250	138
								251	137
								252	81
								253	52
								254	46
								255	25
	2,713,981		3,269,304		3,528,706		3,718,552		3,774,379

Reservoir to R. L. 101.00 — 3,774,000,000 cubic metres.

Contents of low level Reservoir at Assuân.

KILOMETRE	AREA OF SECTION R. L. 93 To R. L. 105	AREA OF SECTION R. L. 93 To R. L. 106	KILOMETRE	AREA OF SECTION R. L. 93 To R. L. 105	AREA OF SECTION R. L. 93 To R. L. 106	KILOMETRE	AREA OF SECTION R. L. 93 To R. L. 105	AREA OF SECTION R. L. 93 To R. L. 106
				452,258	496.103		712,457	788,018
1	31195	32985	51	4251	5002	101	4682	5342
2	5997	6954	52	4992	5737	102	5459	6197
3	9736	10493	53	4305	4964	103	4337	5107
4	12788	13620	54	6312	7117	104	4833	5533
5	9169	9814	55	4385	4994	105	4618	5280
6	9554	10116	56	4385	4994	106	4567	5227
7	8290	8801	57	4385	4994	107	4097	4702
8	8123	8620	58	4385	4994	108	4589	5274
9	10777	11459	59	6848	7321	109	3682	4272
10	12624	13514	60	3505	3950	110	3415	3957
11	8286	8813	61	3492	3929	111	2644	3126
12	11945	11744	62	3797	4344	112	3838	4460
13	8809	9454	63	5449	6019	113	3829	4454
14	9221	9883	64	5971	6601	114	4719	5541
15	8808	9476	65	6011	6601	115	4811	5600
16	9929	10727	66	5669	6429	116	4763	5553
17	11371	12346	67	5172	5780	117	4497	5262
18	14999	16271	68	4862	5402	118	3435	4042
19	11319	12104	69	4865	5432	119	2805	3448
20	8313	9040	70	5384	5954	120	3311	4098
21	8142	8829	71	5316	5911	121	4282	5502
22	11180	12205	72	5544	6139	122	5601	6693
23	5819	6469	73	5470	6085	123	4593	5435
24	9818	10692	74	4073	4618	124	3458	4100
25	7802	8594	75	3767	4234	125	3067	3664
26	7611	8656	76	4020	4595	126	2972	3567
27	11568	12790	77	4382	4977	127	2770	3335
28	7010	7955	78	3991	4361	128	2399	2889
29	8636	9641	79	4337	4837	129	2560	3092
30	9282	10330	80	4498	4996	130	2480	3004
31	7036	7818	81	4609	5119	131	2314	2809
32	8108	9776	82	4943	5488	132	2223	2718
33	5487	6592	83	4722	5289	133	2451	2982
34	7999	9111	84	5085	5712	134	2623	3190
35	8202	9163	85	4246	4746	135	2346	2866
36	7709	8692	86	4345	4877	136	2255	2761
37	7389	8239	87	5140	5760	137	2229	2734
38	6967	7780	88	6128	6868	138	2378	2895
39	7341	8176	89	6576	7371	139	2334	2851
40	6659	7524	90	7174	8014	140	2590	3178
41	6499	7371	91	7324	8177	141	2456	3035
42	6447	7267	92	7086	7968	142	1886	2341
43	7847	8767	93	9289	10406	143	1685	2093
44	8903	9870	94	6823	7750	144	1450	1807
45	8502	9492	95	7766	8648	145	1752	2189
46	8390	9457	96	5030	5692	146	1710	2136
47	9677	10869	97	5423	6113	147	1830	2294
48	9873	11325	98	4947	5584	148	1974	2486
49	1950	2142	99	4533	5118	149	2207	2780
50	4154	4547	100	5277	5964	150	1940	2442
	452,258	496,103		712,457	788,018		872,195	978,356

Contents of low level Reservoir at Assuân [Continued].

KILOMETRE	AREA OF SECTION R. L. 93 To R. L. 105	AREA OF SECTION R. L. 93 To R. L. 106	KILOMETRE	AREA OF SECTION R. L. 93 To R. L. 105	AREA OF SECTION R. L. 93 To R. L. 106	KILOMETRE	AREA OF SECTION R. L. 93 To R. L. 105	AREA OF SECTION R. L. 93 To R. L. 106
	872,195	978,356		909,076	1,026,472		925,818	1,055,105
151	2417	2181	171	1391	1998	191	436	942
152	1886	2397	172	1175	1702	192	310	1127
153	1728	2270	173	1018	1530	193	360	960
154	1588	2122	174	1369	2004	194	249	696
155	1566	2103	175	515	1276	195	375	821
156	1761	2310	176	1247	2036	196	204	764
157	1627	2102	177	1172	1924	197	91	562
158	1786	2348	178	1198	1928	198	82	546
159	1914	2424	179	884	1454	199	34	466
160	2027	2633	180	1002	1699	200	..	592
161	1921	2503	181	495	995	201	..	515
162	1883	2473	182	644	1111	202	..	348
163	2189	2885	183	737	1356	203	..	252
164	1712	2357	184	643	1213	204	..	322
165	1500	1992	185	724	1359	205	..	363
166	1836	2573	186	576	1166	206	..	253
167	2021	2718	187	422	819	207	..	175
168	1927	2668	188	528	1044	208	..	123
169	1697	2428	189	532	1059	209	.	32
170	1895	2626	190	470	970	..	..	..
	909,076	1,026,472		925,818	1,055,106		927,959	1,064,970

Reservoir to R. L. 105.00 — 928,000,000 cubic metres.
Reservoir to R. L. 106.00 — 1,065,000,000 cubic metres.

Contents of the high level Assuân Reservoir.

KILOMETRE	AREA OF SECTION R. L. 96 To R. L. 115	AREA OF SECTION R. L. 96 To R. L. 118	KILOMETRE	AREA OF SECTION R. L. 96 To R. L. 115	AREA OF SECTION R. L. 96 To R. L. 118	KILOMETRE	AREA OF SECTION R. L. 96 To R. L. 115	AREA OF SECTION R. L. 96 To R. L. 118
				801,757	965,795		1,434,652	1,727,067
1	50096	56388	51	14046	17443	101	15048	19293
2	18044	23594	52	13283	16275	102	16026	20278
3	17693	20249	53	12974	16019	103	14349	18354
4	21440	24149	54	16354	19849	104	13156	16636
5	11693	13695	55	10640	12635	105	12330	15472
6	10686	12540	56	10640	12635	106	12313	15628
7	9583	10945	57	10640	12635	107	10681	12983
8	9364	10966	58	10640	12635	108	17405	23345
9	12522	14834	59	8690	10191	109	15767	22067
10	16795	19937	60	8389	9988	110	17035	23980
11	9944	11640	61	8159	9689	111	15718	22273
12	14555	17097	62	10455	12675	112	17690	24050
13	11898	13998	63	11520	13504	113	16992	23097
14	12356	14501	64	12338	14288	114	18442	26384
15	11970	14205	65	13622	16104	115	17469	23379
16	15903	17633	66	13809	16479	116	17825	23645
17	18313	21586	67	14742	17907	117	16275	21405
18	20953	24965	68	11327	13367	118	14616	19288
19	14735	17427	69	11222	13224	119	13791	18808
20	12655	15145	70	11331	13206	120	16934	21179
21	12472	14939	71	11869	13871	121	18338	23415
22	16720	19930	72	12121	14198	122	18444	23196
23	12501	15166	73	12520	14890	123	15453	19533
24	14707	17747	74	10337	12482	124	13397	17619
25	12391	14821	75	9701	11703	125	10815	14257
26	18683	23129	76	9945	12060	126	9966	12793
27	19946	24201	77	10713	12858	127	9402	12079
28	11903	15248	78	9088	10820	128	8006	10031
29	17534	22229	79	9581	11209	129	8657	11124
30	18123	22045	80	10206	12156	130	8683	11015
31	16835	20766	81	10284	12144	131	8810	11667
32	20006	24746	82	10730	12612	132	8788	11465
33	15951	20166	83	11184	13291	133	9267	12364
34	18408	23083	84	13450	16547	134	9251	11846
35	18783	23412	85	10061	12041	135	8476	11041
36	16172	19704	86	11681	14366	136	8140	10505
37	15004	18026	87	11376	14878	137	8150	10325
38	14678	18035	88	13843	16273	138	8183	10305
39	15142	18104	89	15191	17906	139	8163	10177
40	14867	18132	90	17508	20943	140	9294	11934
41	16113	19690	91	19266	23526	141	8882	11463
42	14963	18515	92	20485	25150	142	7351	9646
43	16521	20398	93	24966	30276	143	6377	8301
44	18008	21985	94	19002	23412	144	5597	7074
45	17013	20545	95	18180	21675	145	6644	8339
46	19105	23335	96	12604	15169	146	6473	8273
47	20573	24863	97	13022	15549	147	7294	9581
48	25325	30960	98	12464	15321	148	7563	9495
49	3612	4474	99	11260	13780	149	8406	10618
50	9485	11817	100	15436	19418	150	7546	9676
	801,757	965,795		1,434,652	1,727,067		2,023,435	2,497,768

Contents of the high level Assuan Reservoir [Continued].

KILOMETRE	AREA OF SECTION R. L. 96 To R. L. 115	AREA OF SECTION R. L. 96 To L. L. 118	KILOMETRE	AREA OF SECTION R. L. 96 To R. L. 116	AREA OF SECTION R. L. 96 To R. L. 118	KILOMETRE	AREA OF SECTION R. L. 96 To R. L. 113	AREA OF SECTION R. L. 96 To R. L. 118
	2,023,435	2,497,768		2,410,194	3,011,318		2,674,916	3,439,986
151	6738	8778	201	5997	9397	251	2639	4486
152	7568	9705	202	6077	9669	252	2972	4742
153	7546	9571	203	5788	8672	253	2865	4642
154	7339	9376	204	5587	8032	254	3789	6018
155	7236	9300	205	5792	8897	255	3496	5611
156	7463	9870	206	6535	10352	256	3374	5489
157	6860	8825	207	7157	10987	257	2189	3891
158	7935	10252	208	7414	10984	258	3986	6750
159	8224	10924	209	7827	11104	259	4671	7881
160	8854	11561	210	6337	9532	260	3451	6293
161	8435	11097	211	6737	10484	261	3456	6193
162	8448	11170	212	5876	9178	262	4152	6897
163	9948	13018	213	5800	9450	263	2935	5095
164	8432	10625	214	7211	11627	264	2436	4123
165	7753	10568	215	6501	10366	265	2028	3588
166	10110	13170	216	5580	7695	266	2438	4973
167	9285	11677	217	3980	5510	267	2888	5723
168	9674	12426	218	4587	6342	268	2387	4794
169	9474	12204	219	6347	11034	269	3030	5344
170	10021	12876	220	9219	13534	270	2510	4475
171	8169	10839	221	7333	10895	271	2521	4411
172	7551	10293	222	9558	13464	272	2292	4177
173	7597	10605	223	7430	11670	273	1741	3184
174	8739	11589	224	5993	9998	274	1570	2905
175	8849	11571	225	5108	9384	275	1594	2951
176	9849	12783	226	5371	8986	276	1036	1937
177	9274	12046	227	4908	9406	277	1486	2779
178	9051	11743	228	3190	6479	278	1517	2909
179	7380	10027	229	3821	7435	279	1266	2443
180	8800	11927	230	7008	11328	280	1473	2926
181	8329	11017	231	6283	10348	281	2292	4399
182	8039	11367	232	5381	9472	282	2180	4400
183	7467	9933	233	4998	11800	283	2367	4887
184	7313	10070	234	3529	5246	284	1746	4176
185	7494	10014	235	2870	5754	285	2415	5133
186	7668	9768	236	2480	4741	286	2391	5091
187	5296	7472	237	2871	5671	287	1862	4966
188	5949	8022	238	4987	7522	288	1147	3014
189	5896	7850	239	6930	10699	289	1449	3556
190	5776	7748	240	5478	8453	290	1631	4104
191	5917	7699	241	4293	6916	291	1890	4987
192	9110	11105	242	4076	7481	292	2126	5108
193	7327	9862	243	3533	6353	293	1467	3799
194	6556	8888	244	3148	5518	294	1446	3613
195	6180	8737	245	2794	6892	295	879	2379
196	6479	9021	246	3556	5933	296	769	2723
197	5854	8940	247	3261	5046	297	706	2258
198	5282	7292	248	2708	4283	298	1118	3303
199	5857	8999	249	2493	4443	299	890	4055
200	6368	9300	250	2675	4206	300	1153	4355
	2,410,194	3,011,318		2,674,916	3,439,986		2,785,058	3,657,987

Contents of the high level Assuân Reservoir [Continued].

KILOMETRE	AREA OF SECTION R. L. 96 To R. L. 115	AREA OF SECTION R. L. 96 To R. L. 118	KILOMETRE	AREA OF SECTION R. L. 96 To R. L. 115	AREA OF SECTION R. L. 96 To R. L. 118	KILOMETRE	AREA OF SECTION R. L. 96 To R. L. 115	AREA OF SECTION R. L. 96 To R. L. 118
	2,785,058	3,657,987		2,792,658	3,712,245		792,658	3,733,103
301	1176	3790	321	..	1722	341	..	187
302	981	3315	322	..	1526	342	..	232
303	888	3178	323	..	1663	343	..	142
304	929	3521	324	..	1889	344	..	52
305	830	3515	325	..	1585	..	..	..
306	691	3173	326	..	1463	..	..	..
307	562	2902	327	..	1272	..	..	..
308	260	1745	328	..	1404	..	..	..
309	237	3257	329	..	936	..	..	..
310	262	2772	330	..	780	..	..	..
311	386	3353	331	..	1312	..	..	..
312	219	2469	332	..	962	..	..	..
313	121	1975	333	..	1018	..	..	..
314	58	1820	334	..	605	..	..	..
315	..	1867	335	..	616	..	..	..
316	..	2096	336	..	683	..	..	..
317	..	3162	337	..	542	..	..	..
318	..	2787	338	..	398	..	..	..
319	..	2474	339	..	242	..	..	..
320	..	2087	340	..	240	..	..	..
	2,792,658	3,712,245		2,792,658	3,733,103		2,792,658	3,733,716

Reservoir to R. L. 115.00 — 2,792,000,000 cubic metres.
Reservoir to R. L. 118.00 — 3,733,000,000 cubic metres.

(The slight reduction caused by raising the floor of the undersluices is more than covered by the increase owing to the numerous deep ravines on both banks of the Nile).

Contents of the Kalabsha Reservoir.

KILOMETRES FROM 1st CATARACT	AREA OF SECTION R. L. 96 To R. L. 115	AREA OF SECTION R. L. 96 To R. L. 118	KILOMETRES FROM 1st CATARACT	AREA OF SECTION R. L. 96 To R. L. 115	AREA OF SECTION R. L. 96 To R. L. 118	KILOMETRES FROM 1st CATARACT	AREA OF SECTION R. L. 96 To R. L. 115	AREA OF SECTION R. L. 96 To R. L. 118
				607,533	729,540		1,196,285	1,499,211
			101	15048	19293	151	6738	8778
			102	16026	20208	152	7568	9705
53	12974	16019	103	14349	18354	153	7546	9571
54	16354	19849	104	13156	16635	154	7339	9376
55	10640	12639	105	12330	15472	155	7236	9300
56	10540	12639	106	12313	15628	156	7563	9870
57	10640	12630	107	10551	12953	157	6860	8825
58	10540	12639	108	17405	23345	158	7935	10252
59	8690	10191	109	15767	22067	159	8224	10024
60	8386	9988	110	17035	23980	160	8854	11561
61	8159	9389	111	15718	22273	161	8435	11097
62	10155	12575	112	17690	24059	162	8148	11170
63	11520	13594	113	16992	23007	163	9948	13018
64	12338	11288	114	18412	26384	164	8432	10652
65	13522	16104	115	17469	23379	165	7753	10568
66	13809	16479	116	17825	23545	166	10110	13170
67	14712	17907	117	16275	21405	167	9285	11677
68	11327	13357	118	14616	19288	168	9674	12426
69	11222	13224	119	13791	18808	169	9474	12204
70	11331	13205	120	16031	21179	170	10024	12876
71	11859	13861	121	18338	23115	171	8169	10839
72	12101	14178	122	18444	23196	172	7551	10293
73	12520	14890	123	15453	19533	173	7597	10505
74	10337	12482	124	13397	17619	174	8730	11589
75	9701	11703	125	10815	14257	175	8849	11571
76	9915	12060	126	9966	12793	176	9849	12783
77	10713	12858	127	9402	12079	177	9274	12046
78	9088	10820	128	8016	10031	178	9051	11743
79	9581	11209	129	8957	11124	179	7380	10027
80	10206	12156	130	8683	11015	180	8809	11927
81	10284	12144	131	8810	11667	181	8329	11017
82	10730	12612	132	8788	11465	182	8039	11376
83	11184	13291	133	9267	12351	183	7467	9033
84	13450	16547	134	9251	11846	184	7313	9870
85	10061	12041	135	8176	11041	185	7494	10044
86	11681	14366	136	8140	10505	186	7668	9768
87	13376	16878	137	8150	10325	187	5296	7472
88	13843	16273	138	8183	10305	188	5949	8022
89	15191	17906	139	8163	10177	189	5896	7850
90	17508	20043	140	9294	11934	190	5776	7748
91	19266	23526	141	8882	11463	191	5721	7503
92	20485	25150	142	7351	9646	192	9110	11105
93	24966	30276	143	6377	8301	193	7327	9862
94	19002	23112	144	5597	7074	194	6556	8888
95	18180	21675	145	6614	8339	195	6180	8737
96	12604	15169	146	6473	8273	196	6479	9021
97	13022	15549	147	7294	9581	197	5854	8940
98	12464	15321	148	7568	8495	198	5282	7292
99	11260	13780	149	8106	10618	199	6168	9310
100	15436	19418	150	7546	9676	200	6368	9300
	607,533	729.540		1,196,286	1,499,211		1,583,260	2,012,712

Contents of Kalabsha Reservoir [Continued].

KILOMETRES FROM 1st CATARACT	AREA OF SECTION R. L. 96 To R. L. 115	AREA OF SECTION R. L. 96 To R. L. 118	KILOMETRES FROM 1st CATARACT	AREA OF SECTION R. L. 96 To R.L. 115	AREA OF SECTION R. L. 96 To R. L. 118	KILOMETRES FROM 1st CATARACT	AREA OF SECTION R. L. 96 To R. L. 115	AREA OF SECTION R. L. 96 To R. L. 118
	1,583,269	2,012,712		1,845,770	2,440,481		1,955,912	2,657,469
201	5997	9400	251	2669	4486	301	1176	3790
202	6077	9669	252	2972	4742	302	981	3315
203	5788	8672	253	2865	4642	303	888	3178
204	5587	8032	254	3789	6018	304	929	3521
205	5792	8897	255	3496	5611	305	830	3515
206	6535	10352	256	3374	5489	306	691	3173
207	7157	10977	257	2189	3891	307	562	2902
208	7414	10984	258	3986	6759	308	260	1745
209	8115	11392	259	4671	7881	309	237	2257
210	6337	9532	260	3451	6293	310	262	2772
211	6737	10384	261	3456	6193	311	386	3353
212	5876	9178	262	4152	6897	312	219	2469
213	5809	9459	263	2935	5085	313	121	1975
214	7211	11627	264	2436	4123	314	58	1820
215	6501	10366	265	2028	3588	315	..	1867
216	5580	7695	266	2438	4973	316	..	2096
217	3980	5510	267	2888	5723	317	..	3162
218	4587	6342	268	2387	4794	318	..	2787
219	6347	11034	269	3030	5314	319	..	2474
220	6219	10534	270	2510	4475	320	..	2087
221	7333	10895	271	2521	4411	321	..	1722
222	9558	13464	272	2292	4177	322	..	1526
223	7430	11670	273	1741	3184	323	..	1663
224	5993	9998	274	1570	2905	324	..	1889
225	5108	9384	275	1594	2951	325	..	1585
226	5371	8986	276	1036	1997	326	..	1463
227	4908	9106	277	1486	2779	327	..	1272
228	3490	6979	278	1517	2909	328	..	1404
229	3821	7435	279	1266	2443	329	..	936
230	7008	11328	280	1473	2926	330	..	780
231	6283	10348	281	2292	4399	331	..	1312
232	5381	9472	282	2180	4109	332	..	962
233	4998	11800	283	2367	4887	333	..	1018
234	3529	5246	284	1746	4176	334	..	605
235	2870	5774	285	2415	5133	335	..	616
236	2480	5741	286	2391	5091	336	..	683
237	2871	5671	287	1862	3936	337	..	542
238	4987	7522	288	1147	3014	338	..	398
239	6930	10699	289	1449	3556	339	..	242
240	5478	8453	290	1631	4104	340	..	240
241	4293	6916	291	1890	4987	341	..	187
242	4076	7481	292	2126	5108	342	..	232
243	3533	6353	293	1467	3799	343	..	142
244	3148	5518	294	1446	3613	344	..	52
245	2794	6892	295	879	2376	..	..	..
246	3556	5933	296	769	2723	..	..	..
247	3261	5046	297	706	2258	..	..	..
248	2708	4283	298	1118	3308	..	..	..
249	2993	4443	299	890	4055	..	..	..
250	2675	4606	300	1153	4355	..	..	..
	1,845,770	2,440,481		1,955,912	2,657,469		1,963,512	2,733,193

Reservoir to R.L. 115.00 — 1,964,000,000 cubic metres.
Reservoir to R.L. 118.00 — 2 733,000,000 cubic metres.

(The slight reduction caused by raising the floor of the undersluices is more than covered by the increase owing to the numerous deep ravines on either bank of the Nile).

APPENDIX X.

PROPOSED WADY RAYAN RESERVOIR.

PROPOSED WADY RAYAN RESERVOIR.

TABLE I.

Contents of the Wady Rayan Reservoir.

R. L.	AREA IN MILLIONS OF SQUARE METRES	CUBIC CONTENTS IN MILLIONS OF CUBIC METRES	R. L.	AREA IN MILLIONS OF SQUARE METRES	CUBIC CONTENTS IN MILLIONS OF CUBIC METRES
+ 30	727	20843	— 1	294	5844
29	709	20125	— 2	287	5554
28	691	19425	— 3	280	5270
27	673	18743	— 4	273	4993
26	654	18080	— 5	266	4723
25	636	17435	— 6	260	4460
24	621	16806	— 7	253	4204
23	607	16192	— 8	246	3955
22	592	15592	— 9	239	3713
21	577	15008	— 10	232	3478
20	563	14438	— 11	225	3249
19	546	13886	— 12	218	3028
18	530	13348	— 13	211	2813
17	513	12827	— 14	204	2605
16	497	12322	— 15	197	2404
15	480	11833	— 16	191	2211
14	464	11361	— 17	184	2023
13	447	10905	— 18	177	1843
12	431	10466	— 19	170	1670
11	414	10043	— 20	163	1503
10	398	9637	— 21	152	1346
9	388	9244	— 22	142	1199
8	379	8861	— 23	131	1062
7	369	8487	— 24	120	937
6	359	8123	— 25	109	822
5	350	7769	— 26	99	718
4	340	7434	— 27	88	624
3	330	7089	— 28	77	542
2	320	6764	— 29	66	470
1	311	6448	— 30	56	410
0	301	6142	— 35	38	174
Sea level			— 40	22	22

TABLE II.

Approximate Nile gauges at the proposed Head of the Inlet Canal to the Wady Rayan Reservoir.

August to December 1873 to 1893.

DATES		1873	1874	1875	1876	1877	1878	1879	1880	1881	1882
August	5	3m.2	5m.8	4m.5	4m.9	3m.6	4m.1	5m.1	5m.0	2m.7	2m.5
»	10	3.5	6.4	5.5	5.6	4.0	4.8	5.9	5.9	4.0	3.2
»	15	5.1	6.9	6.9	6.5	4.5	5.3	6.4	6.6	5.9	4.2
»	20	5.6	7.2	6.9	6.5	4.6	5.9	6.8	6.3	4.8	4.7
»	25	5.9	7.4	6.8	6.7	5.3	6.3	6.9	6.0	5.5	5.7
»	31	6.1	7.5	6.9	6.6	5.3	6.6	7.0	5.7	6.0	6.4
September	5	6.2	7.6	6.9	6.8	5.2	6.5	7.1	6.2	6.5	6.4
»	10	6.3	8.1	7.1	7.1	5.2	6.8	7.0	6.3	6.7	6.2
»	15	6.2	8.4	7.3	7.3	5.2	7.1	7.1	6.2	6.7	6.1
»	20	6.2	8.6	7.7	7.6	5.1	7.5	7.6	6.1	6.7	6.1
»	25	6.1	8.7	7.6	8.0	5.0	8.0	8.0	6.1	6.8	6.2
»	30	6.1	8.7	7.5	8.0	5.2	8.4	8.0	6.2	6.9	6.2
October	5	6.1	8.8	7.6	7.8	5.1	8.5	7.8	6.4	6.9	6.0
»	10	5.8	8.6	7.4	7.5	5.0	8.6	7.4	6.2	6.9	5.7
»	15	5.5	7.3	7.3	7.4	4.8	8.6	7.3	6.0	7.4	5.5
»	20	5.3	7.8	7.5	7.0	4.5	8.5	7.1	6.3	7.0	5.7
»	25	5.4	7.4	7.2	6.7	4.3	8.2	7.0	6.2	6.5	5.9
»	31	5.0	6.9	6.8	5.9	4.1	7.8	6.2	6.0	6.0	6.0
November	5	4.5	6.4	6.1	5.3	3.8	7.4	5.9	5.4	5.5	5.4
»	10	4.5	5.6	5.6	4.8	3.6	7.4	5.3	4.8	4.9	5.3
»	15	4.4	5.3	5.1	4.4	3.7	6.9	5.0	4.2	4.5	5.0
»	20	4.2	4.6	4.7	4.3	3.6	6.1	4.7	3.8	4.1	4.7
»	25	4.1	4.4	4.3	4.1	3.4	5.5	4.5	3.6	3.9	4.4
»	30	3.9	4.2	4.1	3.8	3.1	5.1	4.3	3.4	3.6	4.1
December	5	3.8	4.1	3.8	3.5	2.9	4.9	4.1	3.3	3.5	3.9
»	10	3.6	4.0	3.7	3.3	2.7	4.6	3.9	3.1	3.3	3.6
»	15	3.5	3.8	3.5	3.2	2.6	4.4	3.7	3.1	3.2	3.4
»	20	3.4	3.6	3.4	3.0	2.4	4.3	3.6	3.0	3.1	3.1
»	25	3.2	3.4	3.3	2.9	2.3	4.2	3.5	2.8	2.9	2.9
»	31	2.8	3.2	3.1	2.7	2.3	4.0	3.4	2.7	2.8	2.8

TABLE II [*Continued*].

Approximate Nile gauges at the proposed Head of the Inlet Canal to the Wady Rayan Reservoir.

August to December 1873 to 1893.

DATES	1883	1884	1885	1886	1887	1888	1889	1890	1891	1892	1893
August 5	$5^m.4$	$2^m.3$	$5^m.5$	$2^m.9$	$5^m.1$	$2^m.1$	$4^m.1$	$4^m.4$	$3^m.2$	$3^m.8$	$3^m.8$
» 10	6.1	3.3	6.3	3.7	6.3	3.5	4.7	5.5	4.2	5.3	4.7
» 15	5.9	5.5	6.2	4.8	6.8	4.8	5.2	6.0	5.7	5.7	5.5
» 20	5.9	5.5	6.1	5.9	7.0	5.1	5.5	6.2	5.8	5.3	5.2
» 25	6.2	5.2	5.9	6.1	7.2	5.2	5.9	6.5	5.9	5.8	5.5
» 31	6.5	5.3	6.2	6.0	7.1	5.6	6.2	6.7	6.1	6.6	5.6
September 5	6.5	6.1	6.3	5.9	7.3	5.7	6.6	6.9	6.2	6.8	5.5
» 10	6.6	6.0	6.4	5.9	7.7	5.7	6.8	7.1	6.4	7.1	5.5
» 15	6.7	5.9	6.6	6.2	8.1	5.7	6.8	7.3	6.4	7.5	5.5
» 20	6.9	5.7	6.7	6.3	8.2	5.7	6.9	7.4	6.3	7.9	5.7
» 25	7.2	5.6	6.8	6.5	8.3	5.6	6.9	7.5	6.5	8.1	5.8
» 30	7.3	5.7	6.6	6.8	8.2	5.5	7.0	7.5	6.5	8.3	5.9
October 5	6.8	5.6	6.4	6.8	7.7	5.1	7.0	7.5	6.4	8.3	5.8
» 10	7.4	5.5	6.3	6.6	7.6	4.7	6.8	7.3	6.2	8.2	5.8
» 15	7.1	5.4	6.7	6.3	7.3	4.3	6.8	7.0	6.3	8.0	6.0
» 20	6.7	5.3	6.6	6.1	7.0	4.0	6.6	7.1	6.6	7.8	6.1
» 25	6.5	6.6	5.9	6.1	6.7	3.7	6.1	7.2	6.8	7.5	6.5
» 31	6.1	6.0	5.3	5.9	5.5	4.3	6.2	6.8	6.6	7.5	6.1
November 5	5.3	5.7	4.6	4.9	5.2	3.3	5.3	6.3	6.0	6.8	5.4
» 10	4.8	5.6	4.1	4.3	4.6	3.0	4.5	6.0	5.2	6.0	
» 15	4.4	4.9	3.8	3.9	4.3	2.8	3.9	5.4	5.0	5.5	
» 20	4.1	4.5	3.6	3.6	4.0	2.6	3.6	4.8	4.7	4.4	
» 25	3.9	4.3	3.3	3.4	3.7	2.4	3.3	4.3	4.4	5.5	
» 30	3.8	3.9	3.3	3.2	3.6	2.3	3.0	4.0	4.1	4.1	
December 5	3.6	3.7	3.2	3.4	3.4	2.3	3.0	3.8	4.0	4.0	
» 10	3.4	3.4	3.1	3.4	3.2	2.3	2.8	3.7	3.7	3.8	
» 15	3.3	3.3	3.0	3.3	3.1	2.2	2.8	3.5	3.5	3.6	
» 20	3.1	3.1	2.9	3.1	3.0	2.0	2.7	3.3	3.4	3.5	
» 25	3.0	2.9	2.9	3.0	2.9	2.0	2.6	3.1	3.2	3.4	
» 31	2.9	2.7	2.8	2.8	2.9	1.9	2.4	3.0	3.0	3.2	

TABLE III.

Discharges of the Wady Rayan Reservoir Canal.

Bed width 40 metres. Side slopes $1\frac{1}{2}$ to 1. $V = C\sqrt{RS}$ Slope $\frac{1}{10,000}$

DEPTH OF WATER	AREAS	R.	C.	$\sqrt{RS}$	VEL.	DISCHARGE CUBIC METRES PER SECOND
1	41.5	.928	39	.0096	.37	15
2	86.0	1.822	44	.0134	.59	51
3	133.5	2.627	47	.0162	.68	91
4	184.0	3.383	48	.0196	.94	173
5	237.5	4.094	50	.0202	1.01	240
6	294.0	4.772	51	.0218	1.11	326

Bed width 40 metres. Side slopes $1\frac{1}{2}$ to 1. Slope $\frac{1}{20,000}$

DEPTH OF WATER	AREAS	R.	C.	$\sqrt{RS}$	VEL.	DISCHARGE CUBIC METRES PER SECOND
1	41.5	.928	39	.0068	.265	11
2	86.0	1.822	44	.0095	.419	36
3	133.5	2.627	47	.0114	.535	72
4	184.0	3.383	48	.0131	.628	116
5	237.5	4.094	50	.0145	.725	172
6	294.0	4.772	51	.0155	.790	232
7	353.5	5.421	53	.0166	.870	311
8	416.0	6.046	54	.0175	.940	391
9	481.5	6.633	54	.0183	.988	480
10	559.0	7.259	55	.0192	1.056	581

Bed width 80 metres. Side slopes $1\frac{1}{2}$ to 1. Slope $\frac{1}{20,000}$

DEPTH OF WATER	AREAS	R.	C.	$\sqrt{RS}$	VEL.	DISCHARGE CUBIC METRES PER SECOND
1	81.5	.974	39	.0085	.33	27
2	166.0	1.900	44	.0098	.43	71
3	253.5	2.783	47	.0119	.55	140
4	341.0	3.644	48	.0135	.64	220
5	437.5	4.818	51	.0156	.79	346
6	534.0	5.255	53	.0163	.86	460
7	633.0	6.021	54	.0175	.94	595
8	736.0	6.765	54	.0191	1.03	758

WADY RAYAN RESERVOIR.

GENERAL AND DETAILED ESTIMATES OF COST OF WORKS

By Mr. MARSHAL HEWAT.

PROJECT FOR THE INLET CANAL IN THE BAHR BELAMA AND THE OUTLET CANAL BY BUSH.

Summary of cost.

Inlet canal, excavation	L. E.	1,340,960
Outlet canal, excavation	»	436,640
Masonry works	»	327.000
Masonry lining in Inlet canal	»	43,750
Pitching in Inlet and Outlet canals	»	90,000
Diversion of Bahr Yusuf	»	72,000
Closing depressions between Wady Rayan and Fayoum	»	1,200
Land	»	60.000
	L. E.	2,371,550
Contingencies at 10 %	»	237.155
	L. E.	2,608,705

Details of cost of Wady Rayan Reservoir.

Excavation: — Inlet canal in clay	6,986,000	at .04 =	L. E.	279,400
do marl	7,592,000	» .05 =	»	379,600
do rock	8,374,000	» .08 =	»	669,920
do sand	602,000	» .02 =	»	12.040
			L. E.	1,340,960
Outlet canal in clay	10,916,000	at .04 =	L. E.	436,260
Masonry works: — Head regulator Inlet canal			L. E.	47,000
do Bahr Yusuf diversion, &c.			»	188,000
Tail of Outlet canal			»	48,000
2 Syphons on Ibrahimiyeh canal		at L.E. 6,000 =	»	12,000
2 Ralway bridges		» » 10,000 =	»	20.000
6 Minor canal crossings		» » 2,000 =	»	12.000
			L. E.	327.000
Masonry lining in Inlet canal in salty marl	175,000	at .25 =	L. E.	43,750
Pitching in Inlet and Outlet canals	600,000	» .15 =	L. E	90,000
Diversion of Bahr Yusuf excavation	1,800,000	» .04 =	L. E.	72,000
Closing depressions between Wady Rayan and Fayoum	6,000	» .20 =	L. E.	1,200
Land: — Inlet canal	1,100 Feddans	at L.E. 25 =	L. E.	27,500
Outlet canal	1,300 »	» » 32 =	»	32.500
			L. E.	60,000

Estimate of excavation in Wady Rayan Reservoir.

INLET CANAL. — 40 metres bed width in clay and from kilometre 45 to end.

KILOMETRE	DEPTH OF DIGGING			DETAILS OF QUANTITIES			QUANTITIES		
	CLAY	MARL	ROCK	CLAY	MARL	ROCK	CLAY	MARL	ROCK
0	9.4	..	..	54.1 × 9.4	..	..	509	..	..
1	8 1	..	..	52.1 × 8.1	..	..	422	..	..
2	7.9	..	..	51.9 × 7.9	..	..	410	..	..
3	7.5	..	..	51 3 × 7.5	..	..	385	..	..
4	7 5	..	..	51.3 × 7.5	..	..	385	..	..
5	7.3	..	..	50.9 × 7.3	..	..	351	..	..
6	5.9	..	..	48 9 × 5.9	..	..	289	..	..
7	7 0	..	..	50.5 × 7.0	..	..	354	..	..
8	6.4	..	..	49.6 × 6.4	..	..	317	..	..
9	6 3	..	..	49.5 × 6.3	..	..	312	..	..
10	6.0	..	..	49.0 × 6.0	..	..	294	..	..
11	5.8	..	..	48.7 × 5.8	..	..	283	..	..
12	6.2	..	..	49.3 × 6.2	..	..	305	..	..
13	6.3	..	..	49.5 × 6.3	..	..	312	..	..
14	6.3	..	..	49.5 × 6.3	..	..	312	..	..
15	5.8	..	..	48.7 × 5.8	..	..	283	..	..
16	5.8	..	..	48.7 × 5.8	..	..	283	..	..
17	5.9	..	..	48.9 × 5.9	..	..	289	..	..
18	6.2	..	..	49.3 × 6.2	..	..	306	..	..
19	5.8	..	..	48.7 × 5.8	..	..	283	..	..
20	6.3	..	..	49.5 × 6.3	..	..	312	..	..
21	..	7.7	..	..	51.6 × 7.7	..	..	397	..
22	..	19.5	..	..	(52.8) + (67×11.5)	..	..	1184	..
23	..	25.0	..	..	(52.8) + (60×17	..	..	1572	..
24	..	21.7	12 16	.. ..	65 × 21.7 37 × 21.7	50 × 12 29 × 16	.. ..	1110	532
25	..	26.1	12	..	37 × 26.1	28 × 12	..	965	336
26	..	28.1	8	..	36 × 28.1	27 × 8	..	1011	216
27	..	19.6	14	..	37 × 19.6	28 × 14	..	725	392
28	..	11.1	19	..	37 × 11.1	30 × 19	..	410	570
29	..	3 3	23	..	37 × 3.3	31 × 23	..	122	713
30	..	2.6	25	..	37 × 2.6	31 × 25	..	96	775
		sand						7.592	
31	..	..	21.4	..	..	30 × 21.4	..	sand	612
32	..	..	14.5	..	..	28 × 14.5	..	..	406
33	..	..	9.2	..	..	27 × 9.2	..	..	248
34	..	..	10.4	..	..	28 × 10.4	..	..	291
35	..	..	11.4	..	..	28 × 11.4	..	..	319
36	..	..	9.0	..	..	27 × 9.0	..	..	243
37	..	..	8.7	..	..	27 × 8.7	..	..	135
38	..	..	..	..	..	..	..	..	0
39	..	..	..	..	..	..	..	..	0
40	..	..	..	..	..	..	..	..	0
41	..	..	..	..	..	..	..	..	0
42	..	..	..	..	..	..	..	..	0
43	..	..	..	..	..	..	..	..	0
44	..	..	..	..	..	..	..	..	0
45	..	2.5	4.4	..	45 × 2.5	40 × 4.4	..	112	176
46	..	2 4	8.4	..	45 × 2.4	40 × 8.4	..	108	336
47	..	..	7.3	..	..	40 × 7.3	..	..	292
48	..	2.9	10.0	..	45 × 2.9	40 × 10 0	..	130	400
49	..	..	5.7	..	..	40 × 5.7	..	..	228
50	..	..	..	..	..	..	..	..	0
51	..	2.5	..	..	45 × 2.5	..	..	112	..
52	..	.9	..	..	40	..	..	40	..
53	..	1.5	10.0	..	60	40 × 10.0	..	60	400
54	..	..	..	..	..	..	..	..	0
55	..	..	3.0	..	..	40 × 3.0	..	..	120
56	..	1.0	9.0	..	40	40 × 9.0	..	40	360
57	..	..	6.1	..	..	40 × 6.1	..	..	244
						TOTAL.....	6,986	602	8,374

Estimate of excavation in Wady Rayan Reservoir.

OUTLET CANAL. — Bed with 40 metres.

KILOMETRE	DEPTH OF DIGGING			DETAILS OF QUANTITIES			QUANTITIES		
	CLAY	MARL	ROCK	CLAY	MARL	ROCK	CLAY	MARL	ROCK
0	6.3	..	..	49.4 × 6.3	..	..	311	..	..
1	6.6	..	..	49.9 × 6.6	..	..	330	..	..
2	6.1	..	..	49.1 × 6.1	..	..	300	..	..
3	6.2	..	..	49.3 × 6.2	..	..	306	..	..
4	6.2	..	..	49.3 × 6.2	..	..	306	..	..
5	6.6	..	..	49.9 × 6.9	..	..	314	..	..
6	6.4	..	..	49.6 × 6.4	..	..	318	..	..
7	6.0	..	..	49.0 × 6.0	..	..	294	..	..
8	6.7	..	..	50.0 × 6.7	..	..	335	..	..
9	6.3	..	..	49.4 × 6.3	..	..	311	..	..
10	6.1	..	..	49.1 × 6.1	..	..	300	..	..
11	6.1	..	..	49.1 × 6.1	..	..	300	..	..
12	6.2	..	..	49.3 × 6.3	..	..	310	..	..
13	6.4	..	..	49.6 × 6.4	..	..	318	..	..
14	6.9	..	..	50.4 × 6.9	..	..	348	..	..
15	6.3	..	..	49.4 × 6.3	..	..	311	..	..
16	5.8	..	..	48.7 × 5.8	..	..	283	..	..
17	6.5	..	..	49.8 × 6.5	..	..	324	..	..
18	6.4	..	..	49.6 × 6.4	..	..	318	..	..
19	6.4	..	..	49.6 × 6.4	..	..	318	..	..
20	6.9	..	..	50.4 × 6.9	..	..	348	..	..
21	6.8	..	..	50.2 × 6.8	..	..	342	..	..
22	6.9	..	..	50.4 × 6.9	..	..	348	..	..
23	7.1	..	..	50.7 × 7.1	..	..	360	..	..
24	7.5	..	..	51.2 × 7.5	..	..	384	..	..
25	7.5	..	..	51.2 × 7.5	..	..	384	..	..
26	7.4	..	..	51.1 × 7.4	..	..	378	..	..
27	7.6	..	..	51.4 × 7.6	..	..	391	..	..
28	7.9	..	..	51.9 × 7.9	..	..	410	..	..
29	8.0	..	..	52.0 × 8.0	..	..	416	..	..
30	8.7	..	..	53.0 × 8.7	..	..	461	..	..
31	7.9	..	..	51.9 × 7.9	..	..	410	..	..
					GRAND TOTAL..........		10,916 × 1000 = 10,916,000		

WADY RAYAN RESERVOIR.

PROJECT FOR COMBINED INLET AND OUTLET CANAL WITH THE INLET CANAL IN THE DESERT BY BAHR BELAMA AND WADY LIERNUR.

Abstract of cost.

Excavation, Inlet and Outlet canal combined	L. E.	1,440,360
Masonry works	»	225,080
Masonry lining	»	43,750
Pitching	»	90,000
Closing depression	»	1,200
Land	»	30,000
	L. E.	1,830,390
Centingencies 10 %	»	183,039
	L. E.	2,013,429

Details of cost.

Excavation: —

Inlet and Outlet canal combined in	clay	9,480,000	at .04 =	L. E.	379,200
do do	marl	7,592,000	» .05 =	»	379,600
do do	rock	8,374,000	» .08 =	»	669,520
do do	sand	602,000	» .02 =	»	12,040
				L. E.	1,440,360

Masonry works: —

Head regulator		L. E.	47,000
Bahr Yusuf diversion, &c.		»	156,081
1 Syphon on Ibrahimiyeh canal		»	6,000
1 Railway bridge		»	10,000
3 Minor canals crossings	at L. E. 2,000 =	»	6,000
		L. E.	225,081

Masonry lining in salty marl	$2,500 \times 70 \times 1 = 175,000$ at .25 =	L. E.	43,750
Pitching in Inlet and Outlet canal combined	600,000 » .15 =	L. E.	90,000
Closing depression between Wady Rayan and Fayoum	6,000 » .20 =	L. E.	1,200
Land		L, E.	30,000

WADY RAYAN RESERVOIR.

PROJECT FOR COMBINED INLET AND OUTLET CANAL WITH THE INLET CANAL IN THE DESERT BY ESBA ABU HAMID AND WADY LIERNUR.

Abstract of cost.

Excavation in Inlet and Outlet canal combined	L. E.	1,449,550
Masonry works	»	225,081
Masonry lining in salty marl	»	157,500
Pitching in Inlet and Outlet canal combined	»	90,000
Closing depression between Wady Rayan and Fayoum	»	1,200
Land	»	30,000
	L. E.	1,953,331
Contingencies at 10 %	»	195,333
	L. E.	2,148,664

Details of cost.

Excavation: —

Inlet and Outlet canal combined in clay....	9,480,000 at .04 =	L. E.	379,200
do do marl....	11,339,000 » .05 =	»	566,950
do do rock....	6,102,000 » .08 =	»	488,160
do do sand....	762,000 » .02 =	»	15,240
		L. E.	1,449,550

Masonry works: —

Head regulator		L. E.	47,000
Bahr Yusuf diversion, &c		»	156,081
1 Syphon in Ibrahimiyeh canal		»	6,000
1 Railway bridge,		»	10,000
3 Minor canals crossings	at L. E. 2,000 =	»	6,000
		L. E.	225,081

Masonry lining in salty marl .... $9,000 \times 70 \times 1 = 630,000$ at .25 = L. E. 157,500

Pitching in Inlet and Outlet canal combined .... 600.000 » .15 = L. E. 90,000

Closing depression between Wady Rayan and Fayoum... 6,000 » .20 = L. E. 1,200

Land .... L. E. 30,000

WADY RAYAN RESERVOIR.

Details of minor estimates.

Bahr Yusuf diversion.............................	$6,000 \times 50 \times 6 =$	1,800,000 c. m.
Masonry lining to channel in salty marl............	$2,500 \times 70 \times 1 =$	175,000 c. m.
Pitching in Inlet and Outlet canals.................	$20,000 \times 60 \times .5 =$	600,000 c. m.
Ibrahimiyeh Canal, Syphon and Railway bridges similar to corresponding works in Rayah Tewfiki.		

Land: —

Inlet Canal and Bahr Yusuf..................	$\dfrac{26,000 \times 180}{4,200} =$	1,100 feddans
Outlet Canal...............................	$\dfrac{31,000 \times 180}{4,200} =$	1,300 feddans
Closing off depression between Rayan and Fayoum......	$500 \times 6 \times 2 =$	6,000 c. m.

WADY RAYAN RESERVOIR.

BAHR YUSUF DIVERSION MASONRY WORKS.

Down Stream Regulator (1).

Estimate.

Excavation	82,222 c. m.	at .04	=	L. E.	3,288
Wells, foundations	4,950 »	» L. E. 2.5	=	»	12,375
Masonry in floor and superstructure	14,125 »	» .70	=	»	9,887
Ashlar	822 »	» L. E. 2.	=	»	1,644
Stone pitching	8,250 »	» .30	=	»	2,475
Regulating gates	460 »	» L. E. 30	=	»	13,800
Unwatering				»	1,000
			Total	L. E.	43,469

Bahr Yusuf Regulator (2).

Estimate.

Excavation	124,000 c. m.	at .04	=	L. E.	4,960
Wells, foundations	8,803 »	» L.E. 2.5	=	»	22,007
Masonry in floor and superstructure	23,667 »	» .70	=	»	16,567
Ashlar	942 »	» L. E. 2.	=	»	1,884
Stone pitching	9,752 »	» .30	=	»	2,925
Regulating gates	400 sq. m.	» L.E. 30	=	»	12,000
Lock gates	240 »	» » 10	=	»	2,400
Unwatering				»	1,000
			Total	L. E.	63,743

Up Stream Regulator (3).

Estimate.

Excavation	82,000 c. m.	at .04	=	L. E.	3,280
Wells, foundations	4,753 »	» L.E. 2.5	=	»	11,882
Masonry in floor and superstructure	13,500 »	» .70	=	»	9,450
Ashlar	830 »	» L.E. 2.	=	»	1,660
Stone pitching	7,990 »	» .30	=	»	2,397
Regulating gates	640 sq. m.	» L. E. 30	=	»	19,200
Unwatering				»	1,000
			Total	L. E.	48,869

Abstract.

Bahr Yusuf diversion masonry works :—

(1) Down Stream Regulator	L. E.	43,469
(2) Bahr Yusuf do	»	63,743
(3) Up Stream do	»	48,869
Total	L. E.	156,081

WADY RAYAN RESERVOIR.

HEAD INLET REGULATOR FROM NILE (40 metre bed).

Estimate.

Excavation	85,680 c. m.	at .04	=	L. E.	3,427
Wells, foundations	4,636 »	» L.E. 2.5	=	»	11,590
Masonry in floor and superstructure	19,202 »	» .70	=	»	15,441
Ashlar	1,397 »	» L.E. 2.5	=	»	2,794
Stone pitching	4,648 »	» .30	=	»	1,394
Regulating gates	400 sq. m.	» L.E. 30	=	»	12,000
Unwatering				»	1,000
			Total	L. E.	47,646

WADY RAYAN RESERVOIR.

Project for combined Inlet & Outlet canal with the canal in desert by Esba Abu Hamid.

KILOMETRE	DEPTH OF DIGGING			DETAILS OF QUANTITIES			QUANTITIES		
	CLAY	MARL	ROCK	CLAY	MARL	ROCK	CLAY	MARL	ROCK
0	6.3	..	..	49 × 6.3	..	..	154	..	..
1	..	..	..	..	..	..	..	..	..
2	..	..	..	..	..	..	..	..	..
3	..	..	..	..	..	..	..	..	..
4	..	..	..	..	..	..	..	..	..
5	6.6	..	..	50 × 6.6	..	..	330	..	..
6	..	..	..	..	..	..	..	..	..
7	..	..	..	..	..	..	..	..	..
8	..	..	..	..	..	..	..	..	..
9	..	..	..	..	..	..	..	..	..
10	6.8	..	..	50 × 6.8	..	..	340	..	..
11	..	..	..	..	..	..	..	..	..
12	..	..	..	..	..	..	..	..	..
13	..	..	..	..	..	..	..	..	..
14	..	..	..	..	..	..	..	..	..
15	7.5	..	..	51 × 7.5	..	..	382	..	..
16	..	..	..	..	..	..	..	..	..
17	..	..	..	..	..	..	..	..	..
18	..	..	..	..	..	..	..	..	..
19	..	..	..	..	..	..	..	..	..
20	8.5	..	..	52 × 8.5	..	..	442	..	..
21	..	..	..	..	..	..	..	..	..
22	..	..	..	..	..	..	..	..	..
23	..	..	..	..	..	..	..	..	..
24	..	..	..	..	..	..	..	..	..
25	9.2	..	..	54 × 9.2	..	..	248	..	..
21	..	18.3	..	..	416 + (66 × 10.3)	..	..	1095	..
22	..	24.7	..	..	416 + (70 × 16.7)	..	..	1585	..
23	..	33.3	..	..	416 + (72 × 25.3)	..	..	2187	..
1/2	..	47.4	..	1/4	416 + (76 × 39.4)	..	..	852	..
24	..	23.4	..	..	416 + (70 × 15.4)	..	..	1494	..
25	..	20.4	..	..	416 + (67 × 12.4)	..	..	1246	..
26	..	14.9	..	..	416 + (66 × 6.9)	..	..	871	..
27	..	13.2	..	..	416 + (65 × 5.2)	..	..	754	..
28	..	9.3	..	..	416 + (64 × 1.3)	..	..	585	..
29	..	10.6	..	..	416 + (65 × 2.6)	..	..	499	..
30	..	3.0	8.0 12.0	.. ..	57 × 3	52 × 8 33 × 12	.. ..	171	812
		sand						sand	
31	..	2.0	15.0	..	35 × 2	29 × 15	..	70	435
32	..	2.0	16.5	..	35 × 2	29 × 16.5	..	70	478
33	..	2.0	15.0	..	35 × 2	29 × 15	..	70	435
34	..	..	10.1	..	..	28 × 10.1	..	..	283
35	..	..	7.9	..	..	27 × 7.9	..	..	213
36	..	..	11.4	..	..	28 × 11.4	..	..	319
37	..	..	12.0	..	..	28 × 12	..	..	236
38	..	..	8.8	..	..	27 × 3.7	..	..	235
39	..	..	..	..	..	..	..	..	0
40	..	..	1.7	..	..	..	..	..	0
41	..	..	..	..	..	..	..	..	0
42	..	..	..	..	..	..	..	..	0
43	..	..	..	..	..	..	..	..	0
44	..	..	..	..	..	..	..	..	0
45	..	..	..	..	..	..	..	..	0
46	..	2.5	4.4	..	43 × 2.5	40 × 4.4	..	107	176
47	..	2.4	8.4	..	42 × 2.4	40 × 8.4	..	101	336
48	..	..	7.3	..	..	40 × 7.3	..	..	292
49	..	2.9	10.0	..	42 × 2.9	40 × 10	..	88	400
50	..	..	5.7	..	..	40 × 5.7	..	..	228
51	..	..	..	..	..	..	..	..	0
52	..	2.5	..	..	48 × 2.5	..	..	120	0
53	..	.9	..	..	40 × .9	..	..	36	..
54	..	1.5	10.0	..	40 × 1.5	40 × 10	..	60	400
55	..	..	..	..	..	..	..	..	..
56	..	..	3.0	..	..	40 × 3	..	..	120
57	..	1.0	9.0	..	..	40 × 9	..	40	360
58	..	..	6.1	..	..	40 × 6.1	..	..	244
59	..	..	..	..	..	..	..	..	..
						TOTAL.....	9480	762	6102
							Marl	11339	

APPENDIX XI.

REPORT

ON MATTERS CONNECTED WITH THE QUESTION OF NILE RESERVOIRS

CALLED FOR BY

THE UNDER SECRETARY OF STATE OF THE PUBLIC WORKS DEPARTMENT

In his N° 9102 B' of 24th October 1893.

BY R. H. BROWN,

MAJOR,

Inspector General of Irrigation, Upper Egypt.

INDEX.

Letter addressed by Mr. W. E. Garstin, Under Secretary of State, Public Works Department, on the 24th October 1893 sub No. 9102 B', to Major R. H. Brown, R. E, Inspector General of Irrigation of Upper Egypt.

SIR,

I have the honour to forward herewith a copy of a portion of Mr. Willcock's Report upon Nile Reservoirs with the request that you will write me a note upon the questions hereafter specified which more particularly regard Upper and Middle Egypt; this note I propose to print and add as an appendix to Mr. Willcocks' Report, and I would ask you kindly to let me have it, if possible, by the 15th November next, so as to enable me to write my final note upon the project as a whole, and submit it to the Government of Egypt by the end of the current year.

Before detailing the questions upon which I ask your opinion, I would request you to divide the subject into two parts: —

1st. Upper Egypt proper, *i. e.* the country lying between Assuân and Assiut;

2nd. Middle Egypt, or that portion lying to the North of Assiut, including the Fayûm, but excluding Gizeh which will be considered as a portion of Lower Egypt.

Separate replies will then be required to each of the following questions, as regards the two portions of country above mentioned: —

1st — The quantity of water required for the complete summer irrigation of: —

a) The existing cultivated area.

b) The area (if any) possible to reclaim and bring under cultivation.

2nd. — What works could in your opinion be necessary, in order to enable us to take complete advantage of the increased supply, supposing a storage Reservoir to be successfully constructed.

3rd. — The approximate cost of such works.

4th. — The increased Revenue to the country obtainable by such increase of supply.

c) Indirect, as regards land at present cultivated, which would increase in value owing to the assured water supply.

d) Also indirect, as regards land at present under Flood Irrigation only, which would be brought under summer irrigation, thereby rendering a double crop possible.

e) Direct, as regards land at present waste and uncultivated, owing to deficient water supply, which could be rendered culturable, and yield a direct return to the State, both by the sale of such lands, and by the additional yearly taxation which they would bring in.

5th. — Your opinion as to the advisability of suppressing the Basin System, either as a whole, or in part, and what you consider would be the effect of such suppression upon the flood gauges in Cairo and the Delta.

6th. — I should like your opinion given briefly as to Wady Rayan project, both as regards its advisability as a storage Reservoir, and a flood escape Basin, or even whether it might not be better, supposing the Basins to be suppressed and summer irrigation given to their entire area, to use this depression for neither of the foregoing purpose, but simply as an escape for the drainage of Middle Egypt.

As regards **Question 1** I would refer you to Mr. Willcocks' Report, paras. (6) to (22). The figures therein given by him have, I understand, been arrived at after a close consultation with you, and I further understand from him that you and he are at one in accepting these figures as correctly representing the requirements both of Upper and of Middle Egypt.

Question 2.

Under this head will come all necessary changes to canals both as regards their section and their masonry works in order to enable them to usefully distribute a summer as against a flood supply. It will be necessary to consider the advisability of building supplementary Barrages at different points of the River with a view to, by means of the increased water level thus obtained, changing as little as possible the existing canal system.

The Assiut Barrage does not come under this head as that will be considered as a part of Mr. Willcocks' project.

The drainage of the whole country must also be considered and estimated for in arriving at any statement of expenditure likely to be incurred to enable us to make use of an increased water supply.

Question 3.

This is, I admit, a difficult question to answer, and I only expect an approximate reply. With the maps and levels at your disposal, I think you will be able to give me a fairly accurate, though, as I say, only an approximate estimate of the total expenditure to be incurred.

This expenditure will doubtless be spread over several years and a portion of it will doubtless be found from our ordinary Budget.

I do not think it necessary to enter at present into the possible increase of maintenance charges in the future; it would be next to impossible to arrive at a satisfactory answer to this and it is more than probable that what is added to the change of canal clearances will be, to a certain extent, balanced by the diminution in the expenditure upon Basin banks.

Question 4.

Calls for no special remark.

Question 5.

This is really the most important question of all, as upon it, in a great measure, depend your replies to all the other four preceding questions.

I imagine you will agree with me that, until we have arrived at some method for escaping our surplus water in high floods, any complete suppression of the Basin system would be not only undesirable but extremely dangerous to Lower Egypt.

It is upon the extent to which you do consider this suppression desirable that I particularly desire your opinion.

Question 6.

I do not expect you to answer this, except briefly and upon general lines. You have, however, such an intimate knowledge of the question and have studied the Wady Rayan so thoroughly, that your opinion will have the very greatest value, both with me and with the members of the Commission appointed to consider the whole question.

I have, etc.

Signed: W. E. GARSTIN,
Under Secretary of State.

Report on matters connected with the question of Nile reservoirs called for by Under Secretary of State, Public Works Department, No. 9102 B' of 24th October 1893, by R. H. Brown, Major, Inspector General of Irrigation of Upper Egypt.

QUESTION 1.

The quantity of water required for the complete summer irrigation of:—
(a) *The existing cultivated area.*
(b) *The area (if any) possible to reclaim and bring under cultivation.*

Mr. Willcock's figures accepted as to quantity of water required per feddan.

The figures given by Mr. Willcocks on page 7(1) giving "the cubic metres of water required per day per acre commanded" are those which I consider correctly represent the requirements of Upper and Lower Egypt, but I do not know how he has divided Upper and Lower Egypt; probably at Asyût.

As all the basins south of Derût would be on the Upper Egypt system of canals, I propose to make the separation between Upper and Middle Egypt there, both on the east and west of the Nile, and to assume that there is a dam at Asyût, which will bring the water to the country surface at Derût and northwards. But this makes so little difference in the figures that those given in para. 16, page 7 of Mr. Willcocks' report agree nearly with mine, being however in the case of Upper Egypt rather more than 10 per cent, and in the case of Middle Egypt rather less than 10 per cent in excess of mine.

I think it is a good thing to allow this 10 per cent, so I consider Mr. Willcocks' figures should be accepted as they stand.

Areas capable of reclamation.

There is in the Fayûm only a small area, about 50,000 feddans capable of reclamation, and elsewhere in Upper Egypt no reclamation is possible. I have, as the area is so small, included it with the existing cultivated area. The areas used in Mr. Willcocks' cultivations are 1,200,000 feddans for Upper Egypt, and the same Middle Egypt.

Areas Upper and Middle Egypt.

I calculate there are 1,025,000 feddans in Upper Egypt and 1,100,000 in Middle Egypt excluding Gizah. Mr. Willcocks' include Gizah. Adopting Mr. Willcocks' system of tables, the following are the figures calculated from the areas obtained by me:—

Middle Egypt 1,100,000 feddans.

Supply required calculated for Middle Egypt.

MONTH	CUBIC METRES PER 24 HOURS	CUBIC METRES PER SECOND	CUBIC METRES PER SECOND AVAILABLE IN A BAD YEAR	CUBIC METRES PER SECOND DEFICIENT	SUPPLY REQUIRED PER ANNUM FROM RESERVOIR
January	8,800,000	102	102	...	...
February	8,800,000	102	102	...	...
March	8,800,000	102	102	...	...
April	8,800,000	102	90	12	31,104,000
May	8,800,000	102	25	77	206,236,800
June	8,800,000	102	25	77	199,584,000
July 1st to 15th	14,300,000	166	25	141	182,736,000
July 16th to 31st	27,500,000	318	175	143	197,683,200
August	37,500,000	318	318	...	...
September	27,500,000	318	318	...	...
November	12,100,000	140	140	...	...
December	8,800,000	102	102	...	...
			TOTAL PER ANNUM		817,344,000

(1) There is a misprint opposite "July 1st to 15th" where 8 is given instead of 13 in first table.

Upper Egypt 1,025,000 feddans.

Supply required calculated for Upper Egypt.

MONTH	CUBIC METRES PER 24 HOURS	CUBIC METRES PER SECOND	CUBIC METRES PER SECOND AVAILABLE IN A BAD YEAR	CUBIC METRES PER SECOND DEFICIENT	SUPPLY REQUIRED PER ANNUM FROM RESERVOIR
January	8,200,000	95	95	...	...
February	8,200,000	95	95	...	...
March	8,200,000	95	90	5	13,392,000
April	8,200,000	95	...	95	246,240,000
May	8,200,000	95	...	95	254,448,000
June	8,200,000	95	...	95	246,240,000
July 1st to 15th	13,325,000	154	...	154	199,584,000
July 16th to 31st	25,625,000	297	297	...	...
August	25,625,000	297	297	...	...
September	25,625,000	297	297	...	...
October	25,625,000	297	297	...	...
November	11.275,000	130	130	...	...
December	8,200,000	95	95	...	...
			TOTAL PER ANNUM		959,904,000

Thus calculated the quantity of water required from a reservoir for the complete summer irrigation of Middle Egypt is 817,344,000 cubic metres (against Mr. Willcocks' 950 millions) and of Upper Egypt is 960,000,000 (against Mr. Willcocks' 1160 millions).

The reservoir for Middle Egypt would require a maximum discharge of 143 cubic metres and for Upper Egypt 154 cubic metres per second.

Still I consider Mr. Willcocks' figures preferable as they allow a margin for loss between the reservoir and the land to be irrigated.

QUESTIONS 2 & 3.

What would in your opinion be necessary in order to enable us to take complete advantage of the increased supply supposing a storage Reservoir to be successfully constructed.

(1) For Middle Egypt.

(2) For Upper Egypt.

And cost ?

Middle Egypt. Works required. Complication of the question by the Wadi Rayan.

(1) Besides a storage reservoir for Middle Egypt, I assume a dam at Assyût, which will give flow irrigation from Derût northwards; and "Middle Egypt" I consider to begin at Derût. The uncertainty as to the future fate of Wady Rayan complicates the question, as there are three conditions under which the drainage would have to be arranged for, namely : —

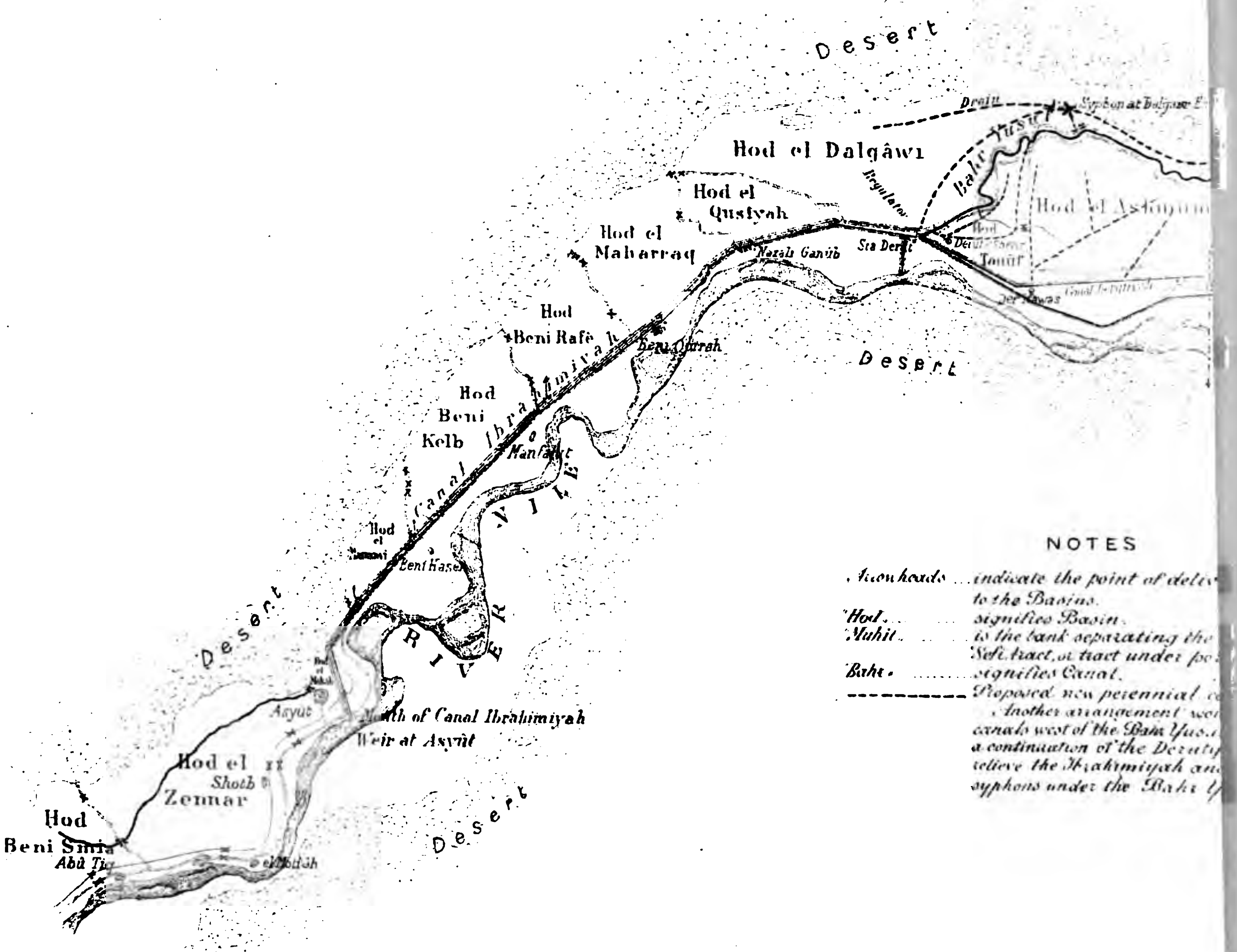
a) With the Wady Rayan as a storage reservoir.

b) With it adopted to serve as a receptacle for the drainage.

c) With it left unused.

In case *(a)* a new main drain on the east of the Bahr Yusif would have to be dug from Lahùn Southwards.

In case *(b)* the Bahr Yusif would become the main drain in cases *(a)* and *(c)* Hod Kosheshah and all the land below R. L. 28.00 would have to be reserved as basin to provide for the drainage during High Nile; or a system of parallel drains as described further on in this note would have to be provided for the drainage.



this note would have to be provided for the drainage.

In any case the Fayûm supply is a difficulty. If the Rayan is made a Reservoir, the flood supply to the Fayûm will be as before from the Bahr Yusif. But the reservoir level will fall too low in summer to give R. L. 22.00 at Medinet El Fayûm which is the level desired there. **Fayum supply difficulty.**

If the Rayan is not used at all, the flood supply for the Fayûm must come from the Bahr Yusif also, or by a back flow from the Kosheshah Escape; Hod Bahabshin-Koshesha being reserved as a Basin. In such a case the drainage water could be kept so diluted by the fresh supply from Derût as not to be injurious. But in the Summer it would not do to feed the Fayûm from a drain which collects the drainage of such a large area.

Hence in both these cases it will be necessary to provide a branch from the Ibrahimiyeh to carry a discharge of 2 mil. cubic metres from about the end of March, over which channel during flood (until the basins South of Derût are also suppressed) the discharge waters of the basins from Asyût to Derût will have to pass.

If the Wadi Rayan is used as a receptakle for drainage and the Bahr Yusif as a drain, we are met with the difficulty of providing a separate canal to carry 7 millions, the flood supply of the Fayûm. The simplest solution of the two conflicting problems of drainage and Fayûm supply appears to be that which is not complicated by any question of the Wadi Rayan, and in which, in Summer, the Bahr Yusif is the main drain, and the Fayûm is fed by a special branch from the Ibrahimiyah, and in flood the Bahr Yusif carries the flood supply of the Fayûm and the Bahabshin-Kosheshah basin is reserved as a basin to provide for the drainage.

On the accompanying map I have shewn, by full red lines the proposed canals for converting Middle Egypt into "Sefi", and by dotted lines a few of the drains. It is absolutely necessary to include the W. of the Bahr Yusif as after the suppression of the Minia basins it will be impossible to raise the Bahr Yusif level sufficiently to flood them. **Map shewing proposed canals.**

The total cost of these canals I estimate to be L. E. 308,500.

The details of the estimate by which I have arrived at these figures I do not give here, but the abstract is as follows: — **Cost of works.**

	CUBIC METRES.
438 kilometres of Main Branches from the Ibrahimiyah canal, 20 cubic metres per m. run average	8,760,000
657 kilometres, of minor branch canals and drains 16 cubic metres per m. run average	10,512,000
Total	19,272,000

Or say 20 millions cubic metres.

Earthwork 20,000,000 at P. E. $1\frac{1}{4}$ .... = L.E. 250,000

Masonry Works: —

Viz: syphon at Dalgawi Escape, 3 syphons under the Bahr Yusif, Heads Regulators	» 41.000
Fayûm Feeder-Earthwork L. E. 7,500, syphon under Basin Escape channel L. E. 10,000	» 17,500
Total	L.E. 308,500

But there has to be added to this estimate the cost of enlarging the Ibrahimiyah as well as that of completing and extending the main drain through Gizah. The following table shews that the present maximum discharges of the Ibrahimiyah canal will be exceeded. **Widening the Ibrahimiyeh Canal.**

Table of present and future maximum discharges.

The Ibrahimiyah Canal.

BELOW REGULATOR	PRESENT MAXIMUM MILLIONS OF CUBIC METRES PER DAY	FUTURE MAXIMUM MILLIONS OF CUBIC METRES PER DAY	NUMBER OF ARCHES IN REGULATOR	REMARKS
Derût.........	13	12 1/2	7	Regulator ample water way.
Minia...........	6 1/4	9 1/4	3	The lock can be made into 2 more openings.
Matai	5	6	6	Ample waterway.
Maghaghah.....	3 1/2	4	5	do do
Sharahnah......	1 3/4	2 3/4	2	Waterway sufficient, but will require strengthening down stream.

The present full supply of the canal fills its channel more especially below Minia and Maghaghah. Berms exist on both sides which might be partly removed.

From Minia to Kolosnah, and from Maghaghah to Feshn and perhaps also to Beni Suef the canal will require enlarging.

In all 60 kilometres will require enlarging. At Beni Suef this can be easily done, less easily from Maghaghah to Feshn, and least easily from Minia to Kolosnah. Above Minia the banks may require strengthening for 10 kilometres.

It may be necessary from Minia to Kolosnah to enlarge the Safsafah, and let it carry 3 millions of the total discharge required (1), and the Minia need not be altered. The Safsafah canal (maximum discharge about 400,000) would be dug anew outside its old channel. This would require for the two canals about 2 millions of cubic metres.

The alterations to the Ibrahimiyah canal may be estimated to cost as follows: —

Alterations to masonry works	L. E.	2,000
Enlargement Minia to Kolosnah, or alternate enlargement of branch canals.	»	40,000
Enlargement Maghaghah to Feshn	»	8,000
Enlargement Beni Suef	»	2,000
Strengthening banks above Minia	»	5,000
	L. E.	57,000

The prolongation of the main drainage line of the Bahr Yusif channel through the Province of Gizah, to enable it to discharge into the Rosetta branch below the Barrage, after passing in syphon under the Rayah Behera, would solve the drainage difficulty in the most satisfactory manner, and allow of the conversion of hods Bahabshin-Kosheshah and Riggah to Sefi cultivation, and also provide for the drainage of Gizah province.

The basin mentioned have an area of about 100,000 feddans.

The drain prolongation would be a channel 110 kilometres in length of 40 metres bed-width and 4 metres depth. Its excavation, the syphon under the Rayah Behera, and the improvement of the Bahr Yusif channel may be estimated to cost L. E. 600,000.

(1) **Note**: It may be better (see note on map) to enlarge canal taking off above Minia and sufficiently to feed the two branches shewn as bifurcating from Abu Bagarah canal and thus avoid necessity of much alteration to Ibrahimiyah.

The estimate of conversion therefore becomes :

Total estimate of Middle Egypt conversion.

Branch canals and drains	L. E.	308,500
Main canal itself	»	57,000
Main drainage	»	600,000
TOTAL	L. E.	965,500

The cost of the Asyût Barrage, which I believe is estimated at L.E. 600,000, would have to be added to this.

Levels connected with question of the Fayûm supply.

In connection with the subject of the Fayûm supply, it may be useful to note here the following levels to show how far it would be possible during a low flood year to feed the Fayûm direct from the Kosheshah escape. A level of 25.90 above the upper of the two bridges is required to give 23.95 down stream of the old bridge which is the maximum level required. This level is required from the 15th August to the 10th November.

In 1888 the Nile rose to 24,00 at Koshesha by the 15th August, and with the exception of a few days below that level by an amount not exceeding 12 centimetres, it remained above 24.00 until the 6th October, the maximum height reached being 24.80. So that in a bad year any arrangement to give the Fayûm its flood supply direct from Kosheshah would fail, though in ordinary years even such as 1893 it might be managed successfully. As regards the summer levels, the Fayûm down stream of old Lahûn Bridge has had during the last few years a lowest water level of R. L. 22.40. To give it 2 millions cubic metres and to preserve the ordinary level maintained at Medinah a down stream of 22.90 is necessary. It is obvious that if the W. L. if the Wâdi Rayan fell to 23.00 in summer it could not produce this level at Lahûn.

Upper Egypt. — Cost of remodelling the canal system.

Upper Egypt. Cost of works.

On p. 46 and following pages of appendices to "Nile Reservoirs" Mr. Willcocks gives an estimate of the cost of remodelling the Upper Egypt canals. Without further study than the time allowed for writing this report provides for, it is useless for me to attempt to make an independent estimate. I think the broad principles as proposed by Mr. Willcocks are suitable viz : — Dams at or near Esna and Dishna and utilisation of those canals which are suitably aligned for the purpose. I consider that the Suhagiyah should be made a drainage line and not an irrigating line, and that from Suhag the Tahtawiyah should carry forward the full supply and not only part of it.

To the one million pounds of Mr. Willcock's estimate there is also to be added half a million for drainage and another half millon for each of the two proposed dams at Esna and Dishna bringing the total up to L. E. 2,500,000.

QUESTION 4.

Increased revenue to the country.

(a) *Indirect, as regards land at present cultivated (? sefi) which would be increased in value owing to the assured water supply.*

(b) *Indirect, as regards land at present under flood irrigation only, which would be brought under summer irrigation, thereby rendering a double crop possible.*

(c) *Direct, as regards land at present waste and uncultivated, which could be rendered cultivable, and yield a direct return to the state, both by the sale of such lands and by the additional yearly taxation which they would bring in.*

Increase to revenue.

The different descriptions of land are thus distributed : —

Middle Egypt.	(Derût to Riggah)
Basin	485,835 feddans
Sefi	389,546 »
Sahel and Nabari	194,000 »
To be reclaimed	40,000 »
Total	1,108,381 feddans

Upper Egypt.	(Aswan to Derût)
Basin	832,580 feddans
Sahel and Nabari	195,000 »
Total	1,027,580 feddans

Data for calculating present and future values of land rents and value of crop.

The value of the land, the rent obtainable and the value of yield per feddan is given below : —

Description of land	Value of land per feddan	Rent paid to owner: owner paying land tax	Value of crop per feddan per annum
	L. E.	L. E.	L. E.
Ordinary basin	12	2 1/2	3 1/4
Best basin	20	4	5 1/4
Worst basin	4	1 1/2	1 1/2
Ordinary Sefi.			
Under present conditions	30	3 1/2	7
With supply assured by reservoir	40	5	9
Best Sefi	50	5 1/2	12
Worst Sefi	15	3	4
Sahel and Nabari.			
Ordinary	15	3	4 1/2
Best	20	4	5 1/2
Worst	12	2 1/2	3

The value of the yield of Sefi land is calculated from the average of 6 years, the period of an ordinary lease.

Example of 6 years rotation of crops.

The contract would begin in September and the rotation would be, for example as follows : —

2 years.

From September 1893 to September 1895...	Bersim (if area rented is small) ploughed up after 2nd cutting to prepare for cane. Cane first year.

1 year.

From September 1895 to September 1896 ..	2nd year's cane, or more generally durah, followed by beans (oqre) planted while the durah is standing.

2 years.
From September 1896 } Bersim (if area is small) ploughed up after 2nd cutting to receive
to September 1898 } cotton followed by beans (oqre) planted while the cotton is standing.
1 year.

From September 1898 to September 1899: Durah and beans (oqre).

When there is an assured supply from a reservoir the value of ordinary Sefi land will increase from L.E. 30 to 40 a feddan and rents will rise from L.E. 3 ½ to L.E. 5 a feddan, while the value of the yield will increase from L.E. 7 to 9 a feddan, and the Basin and Sahil figures will also rise to the same as the increased figures for ordinary Sefi land.

We thus get the following results: —

Middle Egypt.

Tables of present and future values Middle Egypt.

FEDDANS		PRESENT VALUE OF LAND		FUTURE VALUE OF LAND	
		RATE	AMOUNT	RATE	AMOUNT
Basin	485,835	L. E. 12	L. E. 5,830,020	L. E. 40	L. E. 19,433,400
Sefi	389,546	» 30	» 11,686,380	» 40	» 15,581,840
Sahel	194,000	» 15	» 2,910,000	» 40	» 7,760,000
Reclaimed	40,000	» ..	» ...	» 20	» 800,000
TOTAL	1,108,381	.....	L. E. 20,426,400	.....	L. E. 43,575,240

FEDDANS		PRESENT RENT		FUTURE RENT	
		PER FEDDAN	TOTAL	PER FEDDAN	TOTAL
Basin	485,835	L. E. 2 ½	L. E. 1,214,587	L. E. 5	L. E. 2,429,175
Sefi	389,546	» 3 ½	» 1,363,411	» 5	» 1,947,730
Sahil	194,000	» 3	» 582,000	» 5	» 970,000
Reclaimed	40,000	» ..	» ...	» 4	» 160,000
TOTAL	1,108,381	.....	L. E. 3,159,998	.....	L. E. 5,506,905

FEDDANS		PRESENT VALUE OF CROPS PER ANNUM		FUTURE VALUE OF CROPS PER ANNUM	
		PER FEDDAN	TOTAL	PER FEDDAN	TOTAL
Basin	485,835	L. E. 3 ¼	L. E. 1,578,964	L. E. 9	L. E. 4,372,515
Sefi	389,546	» 7	» 2,726,822	» 9	» 3,505,914
Sahil	194,000	» 4 ½	» 873,000	» 9	» 1,746,000
Reclaimed	40,000	» ..	...	» 6	» 240,000
TOTAL	1,108,381	.....	L. E. 5,178,786	.....	L. E. 9,864,429

Thus we see that the value of the land property of Middle Egypt will increase from L.E. 20,426,400 to L.E. 43,575,240 The total rental will increase from L.E. 3,159,998 to L.E. 5,506,905; and the value of the annual yield will increase from L.E. 5,178,786 to L.E. 9,864,429.

Direct increase to revenue.

The profit is to the land owners and the cultivators, and the direct revenue benefits only to the extent of about L.E. 20,000 for the area to be reclaimed in the Fayoum. But Government is also a land owner in Middle Egypt, as the Daïra Sanieh is a Government Estate the value of which will probably be increased by L.E. 3,000,000 in consequence of the assured

supply which the construction of reservoir would give. The rents would rise from L.E. 3 $^1/_2$ to 5 so that the rents received by the Daïra should shew an annual increase of L.E. 400,000 which may be taken as the figure representing the direct increase to the revenue neglecting the above L.E. 20,000.

It is however possible that when there is so much more Sefi land available to meet the demand the rents may not go up so high as I anticipate.

Direct increase to revenue.

What share of the increased profits on the remaining land will indirectly reach the Government treasury I cannot with the time and materials at my disposal pretend to estimate.

Possible sources of increase to revenue.

New factories will spring up and Government might put a tax on all such new establishments. The 485,835 feddans might be taxed up to the rate of the present Sefi land tax which would give at 30 P. T. a feddan, a direct addition of L.E. 151,750 to the land tax. The foregoing tables show separately for Middle Egypt the increased value of the land already under Sefi irrigation due to an assured water supply and also of the land at present under flood irrigation and possibly experts in finance may from these figures be able to deduce what will be the indirect increase to revenue and to them I leave the calculation.

For Upper Egypt the figures are given below: —

Tables of present and future values Upper Egypt.

Upper Egypt.

TOTAL AREAS		PRESENT VALUE OF LAND		FUTURE VALUE OF LAND	
		RATE	TOTAL	RATE	AMOUNT
Basin............	832,580	L.E. 12	L.E. 9,990,960	L.E. 35	L.E. 29,140,300
Sahil and Nabari.	195,000	» 15	» 2,925,000	» 35	» 6,825,000
TOTAL.....	1.027,580	.....	L.E. 12,915,960	.....	L.E. 35,965,300

TOTAL AREAS		PRESENTE RENT		FUTURE RENT	
		PER FEDDAN	TOTAL	PER FEDDAN	AMOUNT
Basin............	832,580	L.E. 2 $^1/_2$	L.E. 2,081,450	L.E. 4	L.E. 3,330,320
Sahil and Nabari.	195,000	» 3	» 585,000	» 4	» 780,000
TOTAL.....	1,027,580	.....	L.E. 2,666,450	.....	L.E. 4,110,320

TOTAL AREAS		PRESENT VALUE OF CROPS PER ANNUM		FUTURE VALUE OF CROPS PER ANNUM	
		PER FEDDAN	TOTAL	PER FEDDAN	TOTAL
Basin............	832,580	L.E. 3 $^1/_4$	L.E. 2,705,885	L.E. 8	L.E. 6,660,640
Sahil and Nabari.	195,000	» 4 $^1/_2$	» 877,500	» 8	» 1,560,000
TOTAL.....	1,027,580	.....	L.E. 3,583,385	.....	L.E. 8,220,640

I have put the future value, rent, and value of produce rather lower than for Middle Egypt on account of the greater remoteness from the export market.

Thus we see that by conversion to Sefi the value of the land of Upper Egypt (South of Derût) will increase from L. E. 12,915,960 to L.E. 35,965,300, the total rental from L.E. 2,666,450 to L.E. 4,110,320 and value of produce from L.E. 3,583,385 to L.E. 8,220.640.

The following Table (C) collects the totals for both Upper and Middle Egypt.

TABLE C.

Table shewing the totals of results for Middle and Upper Egypt.

	PRESENT VALUE OF LAND	FUTURE VALUE OF LAND	INCREASE	PRESENT RENTAL	FUTURE RENTAL	INCREASE	PRESENT VALUE OF ANNUAL YIELD	PRESENT FUTURE OF ANNUAL YIELD	INCREASE
Middle Egypt.....	20,426,400	43,575,240	23,148,840	3,159,998	5,506,905	2,346,907	5,178,786	9,864,429	4,685,643
Upper Egypt.. ..	12,915,969	35,965,300	23,049,340	2,666,450	4,110,320	1,443,870	3,583,385	8,220,640	4,637,255
Totals.....	33,342,360	79,540,540	46,198,180	5,826,448	9,617,225	3,790,777	8,762,171	18,085,069	9,322,898

This table gives much greater future values than those given by Mr. Willcocks.

The data on which these calculations are based are given, so that if they are erroneous, the error can de detected.

QUESTION 5.

"Your opinion as to the advisability of suppressing the Basin system, either as a whole, or in part and what you consider would be the effect of such suppression upon the flood gauges in Cairo and the Delta ".

P. 56 " Nile Reservoirs ".

Effect on Lower Egypt infiltration.

Col. Ross has pointed out that infiltration in Lower Egypt would begin nearly a month earlier than it does now if the basins were suppressed : on the other hand it would probably cease a month earlier so that the duration of the period of infiltration would be the same. But Col. Ross states that the earliness of its appearance would be the cause of increased damage over that which is produced by the present state of things. This is a question for Lower Egypt, but probably this difficulty could be met by the construction of infiltration drains connected with the main drains, and it seems to me that an improved drainage system would meet the case, and this objection to the suppression of the basins would disappear. I am inclined to think that the earlier the infiltration begins to rise to the surface of the land (in Upper Egypt at any rate) the less likely it is to get the better of evaporation.

In August and September the sun is powerfull and the air dry ; in October both these conditions begin to change perceptibly.

Effect on maximum height of floods.

As regards the effect of the suppression of the basins on the maximum height which a high flood would reach, I believe their suppression would tend to produce a lower level than that which is produced under present conditions. The figures collected by the Director General of Reservoirs should decide the point.

If I am wrong, at any rate the increase of the maximum will be but small. A study of the Roda gauges for 1878, 1887, and 1892, years of extraordinary high floods, shows that the maximum levels were reached after the date when the flood due to the maximum at Aswân must have passed Cairo, and were therefore partly due to the water stored in the basins being returned to the Nile.

Were there no basins, the fall at Cairo would follow the fall at Aswân. In 1878 the Roda gauge was over 22 pics up to the 16th November, although by the 10th November Aswân have fallen to 12 pics 10 kirats. The late date of getting rid of the water was I believe most injurious. In 1890 I was with Col. Ross when he got an impatient letter from an Inspector of Irrigation of Lower Egypt, beseeching him to let off the water rapidly, and produce a severe level for a short time rather than prolong the period of high flood to a late date.

Effect produced by opening the Upper Egypt canals.

I have made out from the gauge readings of 1892 and 1893 the figures given in the accompanying table A from which it appears that the opening of the canals with Aswân at 15 pics causes a reduction of the Nile level of 20 to 25 centimetres at the South boundary of Girga, of from 50 to 55 centimetres from Girga to Assyût, and from 60 to 65 centimetres from Assyût to Wasta.

TABLE A.

LOCALITIES	9th TO 12th AUG. 1892 CALCULATED FROM 14 PICS Col. 1	3rd TO 7th SEPTEMBER 1893 15 PICS Col. 2	1st TO 5th OCTOBER 1893 CALCULATED FROM 14 PICS 18 KIRATS Col. 3	DIFFERENCE BETWEEN COL. 1 AND 2	DIFFERENCE BETWEEN COL. 2 AND 3
Aswan	15. Pics	15. Pics	15. Pics	.	..
Ramadi	..	85.48	85.73	.	0.25
Kilh	82.44	82.38	82.62	0 06	0.24
Isna	79.72	79.58	79.86	0.14	0.28
Asfûn	..	79.21	79.44	..	0.23
Armant	77.25	77.09	77.31	0.16	0.22
Fadaliyah	..	75.95	76.24	..	0.29
Escape Aishi	..	75.18	75.35	..	0.27
Shanhuriyah	..	74.44	74.75	..	0.31
Tukh	..	73.38	73.61	..	0.23
Escape Gebelaw	..	71.91	72.17	..	0.26
Head Ghilnsi	..	71.46	71.69	..	0.23
Head Rinnan	..	69.62	69.84	..	0.22
Escape Hamid	..	68.34	68.69	..	0.35
Naga Hamadi	..	67.20	67.50	..	0.30
Rashwaniyah	..	67.08	67.40	..	0.32
Abu Shushah	64.89	64.66	65.00	0.23	0.34
Kasrah	64.86	64.62	64.99	0.24	0.37
Baliana	64.62	64.42	64.66	0.20	0.24
Girga	63.41	63.02	63.21	0.39	0.19
Menshiyah	62.14	61.52	61.81	0.62	0.29
Akhmin	61.06	60.42	60.73	0.54	0.31
Suhag	60.64	59.89	60.13	0.75	0.24
Gez : Shandawil	..	58.79	59.06	..	0.27
Escape Galawiyah	..	57.47	57.68	..	0.21
Khizindariyah	56.96	56.59	56.87	0.37	0.28
Abutig	53.42	52.86	53.29	0.56	0.43
Maanah	..	51.88	52.31	..	0.43
Asyût	51.54	51.08	51.41	0.46	0.33
Hod Beni Hussayn	..	50.21	50.55	..	0.34
Abnub	..	49.65	49.93	..	0.28
Escape Maabdah	..	48.03	48.53	..	0.50
Roda (Asyût)	42.05	41.43	41 65	0.62	0 22
Minia	38.58	37.95	38.28	0.63	0.33
Abu Baragah	..	35.82	36.10	..	0.28
Syphon Sultani	..	30.00	30.33	..	0.33
Biba	29.95	29.36	29.76	0.59	0.40
Syphon Nina	..	28.98	29.26	..	0.28
Head Bahabshin	..	27.87	28.19	..	0.32
Beni Suef	28.12	27.52	27.88	0.60	0.36
Kosheshah	25.40	24.80	25.26	0.60	0.46
Wastah	25.42	24.74	25.17	0.68	0.43
Rodah (Cairo)	19.11	..	19.14	..	..
Barrage	16.38	..	16.25	..	..

Note. — The difference between Cols. 1 and 2 shows the effect on the Nile level of opening the Basin canals, when the Nile is at 15 pics at Aswân. The difference between Cols. 2 and 3 shows the increase on the levels due to 15 pics at Aswân of the 3rd and 17th September observed from the levels of the 1st to 5th October showing that the effect of the canals in lowering the Nile levels has ceased as far as Girga, and from Girga northwards has been decreased by a half or two thirds.

At higher levels the effect would probably be greater. But the difference between the levels with the canals closed and the levels with them worked as at present would not go on increasing at a uniform rate higher the flood, as after 16 ½ pics at Aswân under present conditions, the heads of the canals are partly closed and therefore part of the effect of closing the canals is produced in every high flood.

In a great flood the basins fill rapidly and from, the 10th September, the relief afforded by them rapidly decreases until the 24th September it ceases altogether and changes into the reverse. We may therefore expect the suppression of the basins would produce increased heights of the floods from the 15th August to the 15th September and decreased heights afterwards, as compared with the heights reached before the suppression of the basins. What the amount of these increases and decreases will be Mr. Willcocks will probably have already calculated.

Effect produced by discharge of basins.

The artificial flood produced by the basin discharge will be of course lost to Lower Egypt when the basins are suppressed, which will be a loss in a bad flood year, but a gain in a high flood year. In 1893 an endeavour was made to produce a maximum effect by the discharge of the basins of Upper Egypt, with the result that a fall of 1.08 metres at Aswân from the 9th to the 22nd October was converted into a rise of 0.92 at the Barrage between the corresponding dates, viz: — from 14th to 27th October. The total effect therefore on the Nile at Cairo amounted to a rise in level of 2 metres. The accompanying Table B, shows how this gain was distributed along the Nile valley.

TABLE B.

KILOMETRES FROM ASWAN	GAUGE	CORRESPONDING DATE 1893 FROM OCTOBER	TO OCTOBER	FALL	RISE	REMARKS
359	Wadi Halfah	9th	22nd	1.12	..	
0	Aswân	9th	22nd	1.08	..	
83 ½	Head Ramadi	10th	23rd	.86	..	
122 ½	Kilh Escape	10th	23rd	.96	..	
161	Isna	10th	23rd	.97	..	
167	Head Asfûn	10th	23rd	.90	..	
200	Armant	10th	23rd	.93	..	
215	Fadaliyah	10th	23rd	.63	..	
233	Escape Ashshi	10th	23rd	.71	..	Opened 20th.
240 ½	Head Shanhuriyah	10th	23rd	.77	..	
253	Head Tukh	10th	23rd	.50	..	
281 ½	Escape Gebelaw	10th	23rd	.29	..	Opened 20 th.
292	Head Ghilasi	10th	23rd	.52	..	
309 ½	Head Rinnan	11th	24th	.70	..	
332	Escape Hamad	11th	24th	.72	..	
346	Naga Hamadi	11th	24th	.64	..	
348	Head Rashwaniyah	11th	24th	.58	..	
383	Ascape Abu Shushah.	11th	24th	.54	..	Opened 20th.
383 ½	Head Kasra	11th	24th	.47	..	
389 ½	Baliana	11th	24th	.52	..	
407	Girga	11th	24th	.40	..	
425	Menshiyah	12th	25th	.39	..	
440	Akhmin	12th	25th	.32	..	
447	Suhag	12th	25th	.22	..	Escape opened 21st.
463	Gez: Shandauil	12th	25th	.32	..	
477	Escape Galawiyah	12th	25th	.06	..	Opened.
491	Head Khizindariyah	12th	25th	.17	..	
527	Escape Abu Tig	12th	25th	..	.16	Opened.
540	Head Muanah	12th	25th	..	.23	
546	Asyût	12th	25th	..	.25	
562 ½	Head Beni Hussayn	12th	25th	..	.22	
570	Abnub	12th	25th	..	.24	

TABLE B (*continued*).

KILOMETRES FROM ASWAN	GAUGE	CORRESPONDING DATE 1893		FALL	RISE	REMARKS
		FROM OCTOBER	TO OCTOBER			
598	Escape Maabdeh.....	12th	25th	..	.53	Opened.
628	Derût Escape........	13th	26th	..	..	
660	Rodah (Asyût).......	13th	26th	..	.38	
700	Minya..............	13th	26th	..	.50	
727	Head Abu Bagarah...	13th	26th	..	.65	
769	Maghaghah.........	14th	27th	..	.52	
795	Syphon Sultani......	14th	27th	..	.51	
806	Biba................	14th	27th	..	.59	
810	Mina Syphon........	14th	27th	..	.55	
819½	Head Bahabshin.....	14th	27th	..	.53	
825	Beni Suef...........	14th	27th	..	.52	
857	Kosheshah	14th	27th	..	1.07	Escape opened.
860	Wastah.............	14th	27th	..	.84	
942	Rodah Cairo.........	14th	27th	..	.94	
968	Barrage.............	14th	27th	..	.92	

Effect from basins South of Asyût

As far as Armant along the first 200 kilometres of river from Aswân, the effect produced was slight, and amounted to 15 centimetres. In the next 200 kilometres to Girga about 50 centimetres was added to the 15 of the first 200 kilometres. From Girga to Asyût, a further 68 centimetres was added making the total rise as Asyût 1.33 metres.

From Asyût to Beni-Suef, the rise was further increased by 27 centimetres to which Kosheshah escape discharge added another 40 centimetres making the total north of Asyût 67 centimetres or half that due to the basins south of Asyût. The effect produced by filling the basins in lowering the Nile level is probably proportionate to the effect produced by emptying the basins in raising the Nile level in the ratio of 1 to 2 as roughly speaking the basins fill in 40 days and discharge themselves in 20 days. We may therefore, after making allowance for the discharge required for Sefi irrigation, conclude that the abolition of the basins north of Asyût would increase the flood levels of the Nile from 15th August to 15th September by about 30 centimetres above the levels which, under present conditions the Nile attains between those dates, and that the abolition of the basins south of Asyût would add another 50 centimetres to this increase. the total increase produced at Cairo being 80 centimetres for the period stated. This must not be understood to mean that the *maximum* level would be increased, but only the levels of the dates named. To abolish basin irrigation in Middle Egypt would therefore produce no serious results on the Nile levels but the effect produced by the further abolition of the basins south of Asyût would be more formidable.

Separation of Middle and Upper Egypt.

In making my calculations, I include with Upper Egypt south of Asyût the basin area down to Derût on both sides of the Ibrahimyiah as this would have to be irrigated from the upper (south of Asyût system of canals).

The basins areas are thus : —

South of Asyût..................................	Left bank	746,676	feddans
	Right bank	283,489	»
North of Asyût, Middle Egypt...	Left bank	544,835	»
		1,575,000	feddans

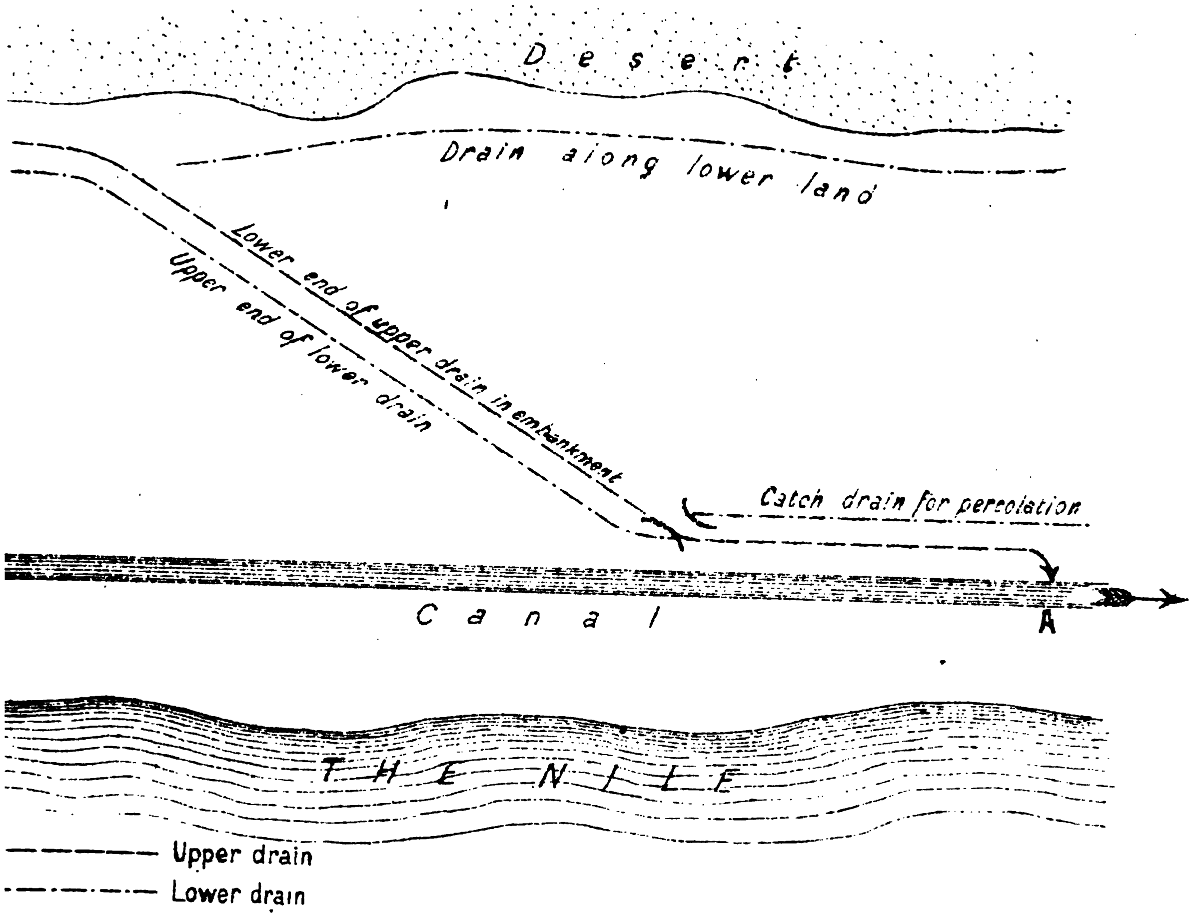
(Not including Gizah).

In note "b" page 59 of "Nile Reservoirs", Sir Colin Moncrieff states that Col. Ross proposes to retain, 182,000 feddans of basins, and adds, that these basins would be sufficiently large to act as moderators of the Nile flood. The balance suppressed would be nearly 6 times this area, so I do not think that, if the total suppression of the basins is calculated to produce dangerously high levels in the Nile, it will remove the danger by retaining only $^1/_6$ or $^1/_7$ of the area as basins to moderate the floods. **Col. Ross's proposal to retain 182,000 feddans of basins.**

But the most important reason that Col. Ross gave for the retention of portions of the basins chains, and which he laid stress on wss the need of providing means to drain the basin areas after conversion to perennial cultivation. **Drainage.**

For Upper Egypt, south of Suhag, there would appear to be only two possible ways of providing for the drainage during the months of high Nile, one of which is that proposed by Col. Ross, viz: — to retain the lower end of certain basin chains as basins, so as to be in a position to allow the water level to rise in them sufficiently to top the Nile flood level.

The other way of providing for the drainage is to adopt a system which has been successful in Italy. The arrangement consists in embanking the lower lengths of each



drain so as to allow the water in the drain to rise higher than the water in the canal into which it would discharge at its tail at **A** (as in the sketch above). The right branch of the drain of the next section would be syphoned under the drain in embankment and would in its turn be embanked along its lower length, and be tailed into the canal. If the admission of the drainage water into the canals is objectionable, the same arrangement could be followed for discharging instead into the Nile through syphons under the canal; but in this latter case the drainage must top the maximum flood of the Nile, and in the former, the high flood level of

the canal. In the lowest section of all, where this system could be extended no farther on account of the local features, a pumping station would be necessary, but only for the service of the one section at the tail of the whole system.

The objection to providing for the drainage as proposed by Col. Ross is that the terminal basins will be deprived of the benefit of Sefi irrigation and there would always remain a certain area at the north end of the Sefi area alongside the boundary of the basin which could not, without a pumping station, be drained during floods. This area could be reduced to a minimum by correctly aligning the basin boundary bank along the contour which is 25 centimetres below the level to which it is necessary that the basin should rise to top the high flood level of the river at the outfall.

The system as followed in Italy does not avoid the necessity of a pumping station at the lower end of the last section, but it elsewhere provides for perfect drainage and admits of the whole area being brought under Sefi cultivation.

From Col. Ross' Map it appears that he retains large areas in Hods Beni-Smia and Zinnar as basin. But I should propose, whichever system of drainage is approved, to suppress the basins from Suhag to Beni Suef entirely, the channels of the Suhagiyah and Bahr Yusif being made the one continuous main drain for this length of the country.

As regards the East of the river and the country on the West of it to the South of Suhag, if Col. Ross' proposed method is selected, Suhag Basin, or a part of it, would remain basin for the draining of the country from Hew to Suhag and the retained areas in other chains would be as proposed by Col. Ross.

There is for the country North of Suhag a third possible means of drainage and were it not for the prohibitive expense necessary to provide this means possibly the best of the three; and that is the utilisation of the Wady Rayan as a receptacle for the drainage, which subject will be considered under question six.

Opinion as regards suppression of basins stated.

My opinion, as regards the suppression of the basin system, is that the basins may without danger to Lower Egypt be entirely suppressed in Middle Egypt, that is from Derût northwards, but that a terminal area at the North end of the chain must be retained as basin to provide for the drainage, unless the alternative system of overlapping drains described before is adopted instead. I think that, if the Basins were also suppressed in Upper Egypt South of Derût, the maximum heights reached by floods would not surpass those reached under present conditions, but the time only of attaining the maximum would be altered and advanced three weeks or a month, except only in the length of river lying between Asyût and Kosheshah, and between Suhag and Abutig, when the effect of reducing the Ibrahimiyah discharge and closing the Suhagiyah would make itself felt in producing higher levels. As the height of the Nile bank in Upper Egypt is nowhere formidable, this change in the flood levels could be met by strengthening the banks to the extent required, for a small expenditure.

It would however, I consider, be wiser to watch the effect produced by the suppression of the basins in Middle Egypt before deciding on their ultimate total extinction throughout the Nile valley and the programme proposed by Sir Colin Moncrieff in para. 2, page 4 "Nile Reservoirs" allow of this being done and I am in favour of a commencement being made on the lines recommended by Mr. Willcocks in para. 36, page 9 of the same report and approved by Sir Colin Moncrieff.

QUESTION 6.

Opinion as to the Wady Rayan project.

In chapter V of my book on "the Fayûm and Lake Mœris" I have given my opinion generally on the utilisation of the Wady Rayan, as:

(*1*) *A flood escape.*
(*2*) *A storage reservoir.*
(*3*) *A receptacle for the drainage of Middle Egypt.*

The Wady Rayan. As a flood escape.

(1) As a flood escape, I do not think the project would be worth the first cost of construction and after expense of maintenance. To reduce the Nile flood by half a metre for a month is the outside that the reservoir would be capable of doing.

To enable it to effect this it would have to be connected with the Nile at Beni Suef or a little to the north of it by a canal carrying 100 millions cubic metres a day. As the suppression of the basins will not materially alter the maxima of high floods except in point of time, a heavy expenditure for the relief of floods is hardly called for (see 5th Question).

As a storage reservoir.

(2) As a storage reservoir, it appears to me to be well adapted and were it not that there are other rival projects with recommendation as regards economy in construction and facilities of filling and emptying which may be judged to establish for them a preference over the Wady Rayan project, I should not hesitate to support the latter. As it is, it appears to me a mere question of expense not only in first construction, but in maintenance charges. The troublesome part of the Rayan project would probably be the feeder canal across the Nile valley which might cause trouble by silting on otherwise shallowing. Suppose the off-take of the combined feeder and outlet canal to be 5 kilometres north of Beni Suef, the canal would have a length of 16 kilometres through high desert, and 26 kilometres through the cultivated land of the Nile valley. The low level of the Nile at the point chosen varies from R.L. 21.25 in bad years to R.L. 21.50 in ordinary years. At R.L. 21.50 the Nile discharge is 410 cubic metres a second, and this must be increased to 510 cubic metres a second to bring the discharge up to the July requirements of Lower Egypt. The Nile level would then become R.L. 21.70. Allowing for a loss of head of 40 centimetres between the Reservoir and the Nile valley and a slope of $\frac{1}{25000}$ across the Nile valley, the total fall would be 1.44 metres, and the lowest level to which the Reservoir could empty would be $(21.70 + 1.44) = 23.14$. We may call this R.L. 23.00 for purposes of calculation.

The Reservoir would be filled to R.L. 27.00 by the Bahr Yusif alone, after it was once in working order, since, when a dam has been made at Asyût, and the Middle Egypt basins are suppressed, the Bahr Yusif can supply 20 millions cubic metres for 5 months (September to January) and 10 millions for one month (February), total 3,300 cubic metres.

The contents of the Wady Rayan from R.L. 23.00 to R.L. 27.00 would be 2,473 millions cubic metres, and, allowing one metre for evaporation during the 5 months of filling the total supply annually required would be 3,091 millions cubic metres. The Reservoir would return to the Nile valley, after deducting one and a quarter metres for evaporation, 1,700 millions cubic metres. Now, Lower Egypt requires (Page 9 of Mr. Willcock's report) a reservoir capable of supplying 1,500 millions cubic metres per annum with a maximum discharge in July of 200 cubic metres a second. The Wady Rayan Reservoir could therefore possibly supply the full requirements of Lower Egypt. As the Wady Rayan, once filled, could be raised every year from R.L. 23. to 27. by the Bahr Yusif without help from the Nile inlet and outlet channels it would be better to remove the Nile off-take of this channel further north to near Ashmant, so as to draw off from the Reservoir to a lower level. But this would necessitate a longer canal, and what is worse, an alignment through land, which the borings

show to be most unfavourable. Such a change would also be unfavourable for the first filling of the Reservoir and would prolong the period which would elapse from the completion of the works and the date on which benefit would first be derived from the expenditure incurred.

In my book referred to above, I allowed for separate in-flow and out-flow channels and hence got a greater depth of water from the Reservoir, as my supposed outfall was at Wastah. But two channels would increase the total of the estimate to a prohibitive figure, and I assume here there will be only one.

Once filled, the Reservoir could be kept working by the Bahr Yusif alone (if the basins in Middle Egypt are suppressed), and the silting up of this feeder canal might be prevented by shutting out the Nile. It seems to me therefore that the only objection that can be raised to this project is its first cost, as compared with other projects, and the time it would take to fill the reservoir to the level at which it would begin to be serviceable. As regards its cost, it has this advantage over its Nile valley rivals, that all the work will be done in the dry, and its cost can be estimated closely beforehand. But the expenditure necessary to connect the Wady Rayan with the Nile by a canal capable of discharging 300 cubic metres a second (25 millions cubic metres a day) when the reservoir is falling from R.L. 24 to 23 is a high one. Mr. Willcocks has estimated for a canal to discharge a maximum in July of 125 cubic metres only and has given his canal across the Nile valley a slope of $\frac{1}{10,000}$. By so doing, he has been able to reduce the cubes necessary and therefore the estimated cost of the work. But under such conditions, the Reservoir can only discharge back into the Nile a layer of 2 metres (after allowing for loss of 1 metre by evaporation) and the needs of Lower Egypt are not met. Mr. Willcocks'estimate amounts to L.E. 2,013,000. But if the Reservoir is to meet the full requirements of Lower Egypt, namely to discharge 1,500 millions cubic metres a year with a maximum discharging power of 25 millions cubic metres at lowest water, the rock channel must be widened from 25 metres base to 36 metres, and the rest of the channel be widened from 40 to 60 metres bed-width and be increased in depth from 4 to 6 metres. This will necessitate an addition to the estimate calculated as under: —

Desert Channel: —			
$2\frac{1}{2}$ kilometres Marl widening to 60 metres.	3,300,000		
Deepening 2 metres........................	300,000		
Cubic metres.....	3,600,000 at 5 P.T. =	L.E.	180,000
7 kilometres rock widening to 36 metres	1,090,000 at 8 P.T. =	»	87,200
Nile Valley: —			
Widening to 60 metres, deepening 2 metres....	9,000,000 at 4 P.T. =	»	360,000
Excess on masonry works..		»	25,000
» Land..		»	10,000
		L.E.	662,200
Contingencies at 10 %..............................		»	66,220
		L.E.	728,420

The total cost will therefore be: —

Original estimate..................................	L.E.	2,013,000
Addition as above..................................	»	728,420
	L.E.	2,741,420

The quantity which this reservoir would discharge to supplement the Nile or to be otherwise utilised per L.E. 1 of expenditure would be $\left(\frac{1,700,000,000}{2,741,420}\right) = 620$ cubic metres, and considered as a reservoir for Lower Egypt being nearer its work a less allowance for loss between reservoir and field would have to be allowed.

In making therefore any comparison between the different Reservoirs schemes, some allowance should be made to the advantage of the Wady Rayan on this account, but making the largest reasonable allowance, the cost is so great as to make it not improbable that its costliness may cause its rejection in spite of all that can be said in its favour. As regards the original project, sketched out by Col. Western in which the feeder canal ran along the inner slope of the Fayûm, I am decidedly opposed to such a canal as constituting a great danger for the Fayûm and being certain to ruin the strip of land lying between the canal and the drainage line which runs along the bottom of the incline below it. The canal bank would have to be formed of a peculiar clay which readily dissolves in water into the most unstable description of slush, and which is therefore quite unsuitable for forming a bank to retain water. I am decidedly in favour of the alignment which Mr. Willcocks has chosen along the Bahr Bilama through the depression, the highest point of which is R. L. 54.90. His alternative line, which is estimated to cost slightly more, is not, in my opinion, nearly such a satisfactory line.

The Wadi Rayan as a drainage receptacle.

If the comparison of the different estimates is unfavourable to the Wady Rayan project, and this, on the objection that it requires so long to fill, condemns it as a project for the storage reservoir, there remains the question whether it is worth while to connect it with the Nile valley to provide drainage for Middle Egypt, and for the country as far south as Suhag on the west of the river. The area, for which it would afford a means of drainage from Suhag to Beni Suef, is about 1 million feddans. Assuming that the drainage is $^1/_3$ of the discharge required for irrigation, the total drainage per annum would be 1,615 millions cubic metres. The evaporating surface of the Wady Rayan between say R. L. 18 and 22 is about 550 millions square metres. Evaporation for the 12 months of the year in Cairo is 2,364 metres. In the Wadi Rayan surrounded by desert it would probably be more. If we take it at 2.40 metres, the yearly evaporation between the levels stated above will amount to 1,320 millions cubic metres so that the drainage would gain on the evaporation. But it would be many years before the Wady Rayan could fill up to R. L. 23, and, even if it did, the lake could be sufficiently lowered in summer by a connection with the Nile, to fit it to receive all that it would be required to during the next flood season. During winter and summer drains back into the Nile would help.

If the Wady Rayan were devoted to this purpose, the difficulty of drainage would be solved but not the problem of the Fayum supply. If it is made a storage Reservoir, the Bahr Yusif will not be available for the main drain of the district, and a new main drain parallel to its general course along the lowest part of the valley, would have to be dug for some distance, which would add considerably to the contingent costs of the Rayan project.

R. H. Brown,

Major,

Inspector General of Irrigation Upper Egypt.

15th November, 1893.

APPENDIX XII.

NOTE

ON THE UTILIZATION OF RESERVOIR WATER

IN THE

GIZEH PROVINCE AND THE DELTA,

BY E. W. P. FOSTER,

Inspector General of Irrigation of Lower Egypt.

Letter addressed by W. E. Garstin, Under Secretary of State, P. W. D., on the 21st October 1893, No. 9103 B' to Mr. E. W. P. Foster, Inspector General of Irrigation of Lower Egypt.

SIR,

I have the honour to forward herewith a copy of a portion of Mr. Willcocks' Report upon the proposed Reservoir in Upper Egypt. I would ask you kindly to write me a note upon the question therein raised, more particularly affecting Lower Egypt; this note I propose to print and add as an appendix to Mr. Willcocks' Report, and I should be greatly obliged by your letting me have it, if possible, by the 15th November next, in order to enable me to write my own note upon the whole question and submit it to the Egyptian Government by the end of the current year.

The questions upon which I should wish your opinion are:

1. — The quantity of water required for the complete summer Irrigation of Lower Egypt.

a) As regards the existing cultivated area.

b) As regards the area of land possible to reclaim and bring under cultivation.

2. — What works would in your opinion be necessary in Lower Egypt in order to enable us to take advantage of the increased supply, supposing a storage reservoir to be successfully constructed.

3. — The approximate cost of such works.

4. — The increased Revenue to the country obtainable by such increase of supply.

c) Indirect, as regards the lands at present cultivated, which would be increased in value owing to the assured water supply.

d) Also indirect, as regards land at present under flood Irrigation only, which could be brought under summer Irrigation.

e) Direct, as regards land at present waste and uncultivated owing to deficient water supply, which would be rendered culturable and yield a direct return to the State, both from the price derived from its sale and from the early taxation to be obtained from it.

As regards question (1) I would refer you to Mr. Willcocks' Report, paragraphs 8 to 20.

The figures therein given by him have, I understand, been arrived at after a close consultation with you, and I further understand from him that you and he are at one regarding the correctness of the figures given as representing the requirements of Lower Egypt.

Question 2.

This is a very big and important question:

Undoubtedly in order to enable us to make full use of the water obtainable very great changes will be necessary in the present system of canals.

Probably many in the main branches would have to be enlarged, and considerable alterations made in existing masonry works.

I would ask you to consider in relation to this question whether it would not, with a view to the better irrigation of the low lands to the north of he Delta, be preferable and in the end cheaper, to erect secondary barrages in both branches, by which means water might be delivered at a high level in existing canals and the expense of heavy alterations in the irrigation system where it passes through the rich cultivation and the valuable high land

lying further to the south be thus avoided. I myself incline to the construction of these secondary barrages both as enabling us to use our water more economically and avoiding the very long lines of channel, taking off upstream of the Barrage.

I would ask you further to consider whether it might not be advisable to construct small barrages at Damietta and Rosetta with a view to preventing the influx of the salt water in summer and at the same time enabling the people living along the river banks to make use of the fresh water thus ponded up.

Above all, the question of drainage should be taken up. Undoubtedly, if we are going to have a permanent increased supply and if we are going to bring fresh land under cultivation, very considerable expenditure must be incurred in this direction and this work should, in my opinion, be put in hand simultaneously with the construction of the new Reservoir.

Question 3.

This is I admit difficult to answer: detailed estimates are out of the question and I do not think are at present called for.

With the maps and levels at your disposal I think, however, you could give me a fairly, accurate although approximate estimate of the total expenditure to be incurred. This expenditure will doubtless be spread over a series of years and a portion of it be charged to our ordinary budget.

It is most necessary, in order to place the financial question fairly before the Government that some idea of the expenditure on the above works be arrived at, as the Reservoir itself would be of little use to us, were the changes in our irrigation system, which would enable us to make use of the extra water, not carried out.

Question 4.

Calls for us special remarks. One last point I would ask you to give your opinion upon.

Supposing the Wady Rayan depression were to be used as a flood escape reservoir (with a view to reducing the height of dangerous floods in the Delta) what in your opinion should be the minimum discharging capacity of the canal of communication between it and the Nile, so as to enable it to effectually reduce the danger caused by the floods above alluded to.

I have the honour, etc.

Signed: GARSTIN.

REPORT

On the utilization of reservoir water in the Ghizeh Province and the Delta, by E. W. P. Foster, Inspector General of Irrigation of Lower Egypt.

INTRODUCTION.

The points to be reported on are : —

1. — Quantity of water required to secure the full irrigation of :
   a. Existing cultivated area.
   b. New lands capable of being reclaimed.
2. — New works required and modification to existing works necessary to ensure the full use of the increased supply.
3. — Probable cost of new works and modification of old ones.
4. — Probable financial benefit to the country.

It need scarcely be remarked that many of the figures are quite approximate but every endeavour has been made to have them as correct as possible.

Question. — *Quantity of water required for the complete summer irrigation of Lower Egypt.*

1. — WATER SUPPLY.

Nothing need be said on what is well known, viz: that the quantity of water needed, varies with the season. Roughly speaking, it increases steadily from 1st March until the 30th June, but early in July, the quantity used owing to the irrigation of lands to be prepared for dura cultivation, increases enormously.

Finding that available figures, given by the Finance Ministry, do not quite agree with those quoted by Mr. Willcocks, it will be as well to use the former which are the larger. Conclusions arrived at in this report are based thereon.

Mr. Willcocks gives present cultivated area......................	Feddans	2,740,000
Probable reclaimable area.........	»	600,000
Total feddans.....		3,340,800

Whereas I find the following are as to be more correct :

Taxed area 1892..	Feddans	2,614,431
Government land paying rent..............................	»	93,372
Conceded lands not paying taxes but partially cultivated, and land in Ghizeh north of Barrage..	»	100,000
Total feddans......		2,807,803

or in round figures say 2,810,000.

My experience leads me to believe that the area capable of reclamation exceeds 600,000 feddans. However I am retaining Mr. Willcocks total of feddans.	Feddans	3,340,000
Of which area at present irrigated..............................	»	2,810,000
Leaving reclaimable...	Feddans	530,000

All lands, both those at present cultivated and the whole, when expanded by increased supply, may be divided into three classes: —

a) High, sweet, old lands capable of producing dry crops without even occasional washing. I assume these to cover 2,300,000 feddans and to require 9 m³ per feddan per day over the whole area, allowing for 1/3 only as under sefi crops.

b) Low-lying old lands growing dry crops, but occasionally requiring washing which is done by periodically planting rice. These lands I take to be 350,000 feddans, nearly half of which is under sefi cultivation each year, and requiring an average of 12 m³ per feddan per day over the whole area.

c) Reclaimed lands, growing for the most part rice though the higher and sweeter parts are occasionally put under cotton, say 160,000 feddans, nearly 2/3 the whole area is under sefi cultivation requiring an average of 25 m³ per feddan per day over the whole area.

a. *As regards the existing cultivated area.*

Applying the above figures, we find that to secure good irrigation for existing cultivated lands, the following discharges are required.

I should note that these figures refer to the month of June only.

Discharges required in March, April and May will be mentioned further on.

	MILLION M3 PER DAY
2,300,000 feddans, class (a) at 9 m³	= 20.7
350,000 feddans, class (b) at 12 m³	= 4.2
160,000 feddans, class (c) at 25 m³	= 4.0
Total millions m³	= 28.9
Say	29.0

This discharge would probably ensure ample water for the whole crop.

b. *As regards the area of land possible to reclaim and bring under cultivation.*

Applying the same rule to the expanded area, that is to say the area after the reservoirs have been in use a sufficient length of time to allow of the whole 3,340,000 feddans being put under cultivation, we find the following discharges; these are likewise those for the month of June only.

2,640,000 feddans, class (a) at 9 m³	= 24
400,000 feddans, class (b) at 12 m³	= 4 1/2
300,000 feddans, class (c) at 25 m³	= 7 1/2
Total millions m³	= 36

Less water is required in May than in June, both the area requiring irrigation and the heat being less, in like manner less is required in April than in May, and less in March than in April.

The following is roughly the distribution of summer supply.

MONTH	FOR PRESENT CULTIVATED AREA	FOR EXPANDED CULTIVATED AREA	INCREASED SUPPLY FOR INCREASED AREA
March	22	25	3
April	22	25	3
May	25	30	5
June	29	36	7
TOTAL	98	116	18

Whereas Mr. Willcocks' total for these four months is 109 millions m^3 per day, that is 7 millions less than shown above. It will however be shown further on that I estimate a smaller quantity in July than that provided by Mr. Willcocks, this will balance portion of the excess of 7 millions shown above.

The discharge for July is examined separately because the area requiring irrigation increases enormously by preparation of land for dura sowing, which commences, or would better be commenced, early in the month.

The area put under dura is not accurately known, on high lands it must be half, if not more, of the total area. In low lands it is no doubt much less. Something less than $^1/_3$ the whole area may be assumed. Upwards of 36 m^3 per day is required.

The quantities of water necessary will therefore be: — MILLIONS

For present area 900,000 feddans at 36 m^3 per feddan per day............... 32 $^1/_2$

For expanded area 1,000,000 feddans at 36 m^3 per feddan per day........... 36

This enormous increase, however, is not all necessary on the 1st of the month, a few millions extra will be needed in the early days, but the discharge will have to be increased slowly until the maximum is reached by the end of the month.

The total requirements at the end of July, viz: for sefi and dura crops will be: —

For present area 29 + 32 $^1/_2$ millions m^3 per day..................... = 61 $^1/_2$

For expanded area 36 + 36 millions m^3 per day..................... = 72

The average throughout the month may be taken at: —

For present area millions m^3 per day 48

For expanded area millions m^3 per day.............................. 56

Whereas Mr. Willcocks allows for an average of 59 $^1/_2$ millions for the expanded area.

With the help of these figures, it will be possible to arrive at a fairly accurate idea of the total volume of water, which will have to be stored in the reservoirs for the benefit of the Delta. This is found by deducting the natural discharges of the river, using for the purpose the discharges of the worst years, from the discharges given in the report as necessary.

On page 8 of the report Mr. Willcocks gives the amount of water which was available for irrigation in the two years of 1887 and 1889.

On pages 6 and 8 of this report are given the quantities required for full irrigation of the present cultivated area, and of the expanded area.

The following statement shows much water the reservoir will have to store to provide the required dicsharges.

For the present cultivated area.

MONTH	DISCHARGES IN MILLION M^3				
	DISCHARGE NECESSARY PER DAY	DISCHARGE AVAILABLE IN RIVER IN BAD YEARS PER DAY	DIFFERENCE BEING EXTRA DISCHARGE NECESSARY PER DAY	NUMBER OF DAYS IN MONTH	VOLUME TO BE STORED IN RESERVOIR
March..............	22	26	..	31	..
April...............	22	23 $^3/_4$	..	30	..
May................	25	21 $^1/_8$	3 $^7/_8$	31	120
June	29	19 $^1/_2$	9 $^1/_2$	30	285
July..............	48	32	16	31	496
TOTAL	..	..	..	..	901

For the expanded area.

MONTH	DISCHARGES IN MILLIONS M^3				
	DISCHARGE NECESSARY PER DAY	DISCHARGE AVAILABLE IN RIVER IN BAD YEARS PER DAY	DIFFERENCE BEING EXTRA DISCHARGE NECESSARY PER DAY	NUMBER OF DAYS IN MONTH	VOLUME TO BE STORED IN RESERVOIR
March	25	26	..	31	..
April	25	23 $^3/_4$	1 $^1/_4$	30	38
May	30	21 $^1/_8$	8 $^7/_8$	31	275
June	36	19 $^1/_2$	16 $^1/_2$	30	495
July	56	32	24	31	744
TOTAL	..	..	..	.	1552

The above tables show that for the present cultivated area, 90 millions m³ would have to be stored in the reservoir to ensure the discharges, shown in this report as necessary.

For the expanded area 1552 millions m³ would be necessary, whereas Mr. Willcocks, on page 9 of his report, puts down the quantity at 1500 millions. The difference therefore between his and my figures is 52 millions, which is only 3 $^1/_2$ p. c., my estimate being the larger.

Before passing on to an examination of works necessary, it will be convenient to explain how the areas and discharges are divided between the different groups of provinces.

The following figures for taxed and Government rented areas have been taken from the annual report for 1892, and I have made an allowance for conceded lands not paying taxes, but which are cultivated.

CIRCLE	PROVINCE	AREA IN FEDDANS				TOTAL FOR EACH CIRCLE
		PAYING TAX	GOVERNMENT LAND RENTED	CONCEDED NOT PAYING TAX	TOTAL	
First	Qalioubieh	187,143	1,541	..	188,684	1,121,197
	Sharkieh	451,340	7,947	15,000	474,287	
	Dakahlieh	443,128	5,098	10,000	458,226	
Second	Menoufieh	349,528	2,222	..	351,750	1,136,852
	Gharbieh	667,561	72,541	45,000	785,102	
Third	Behera	515,731	4,023	25,000	544,754	549.754
	Ghiseh	15,000	..	..	15,000	
	TOTAL	2,619,431	93,372	95,000	2,807,803	2,807,803

The expanded area may be taken as follows:

CIRCLE	PROVINCE	AREA IN FEDDANS — AS ABOVE	TO BE RECLAIMED	TOTAL AREA	TOTAL FOR EACH CIRCLE
First	Qaliozbieh	188,684	..	188,684	1,273,197
	Sharkieh	474,287	102,000	576,287	
	Dakahlieh	458,226	50,000	508,226	
Second	Menoufieh	351,750	..	351,750	1,411,882
	Gharbieh	785,102	275,000	1,060,102	
Third	Behera	544,754	100,000	644,754	654,951
	Ghiseh	5,000	* 5.197	10,197	
	TOTAL	2,807,803	532,197	3,340,000	3,340,000

Although not strictly correct, the distribution of water may be considered as directly proportionate to the area.

June's supply will thus be divided:

CIRCLE	DISCHARGE IN MILLION M^3 PER DAY — PRESENT AREA	EXPANDED AREA
1st	11 1/2	13 3/4
2nd	11 3/4	15 1/4
3rd	5 3/4	7
TOTAL	29	36

However owing to the comparatively large area of Bararis in the Behera Province, the quantity of water apportioned to the 3rd Circle should be somewhat greater than shown above.

July's supply will be divided in the same proportion. The maximum discharge, namely that to be provided by the end of the month, only is taken into consideration.

CIRCLE	DISCHARGE IN MILLION M^3 PER DAY — PRESENT AREA	EXPANDED AREA
1st	24 1/2	27 1/2
2nd	25	30 1/2
3rd	12	14
TOTAL	61 1/2	72

Having estimated the distribution of water between the three sections of the Delta, I will pass on to an examination of the means to be employed in utilising it.

* These 5,197 feddans in Ghiseh are not reclaimable lands, but those at present under basin system or dependent on the Nile direct.

Question. — *What works would in your opinion be necessary in Lower Egypt in order to enable us to take advantage of the increased supply supposing a storage reservoir to be successfully constructed.*

2. — WORKS NECESSARY TO ENSURE FULL USE OF WATER SUPPLY.

Drainage being just as important as irrigation, it would be fatal to the welfare of the country to give a large increase of irrigation water without providing means of drainage. Indeed much, if not all, of the new low lying lands for which water is to be provided, could not be rendered fit for cultivation, without first providing means of drainage.

There are in consequence two classes of works to be considered :

a) Irrigation, or those necessary to carry water from the river to the lands.

b) Drainage, or those works necessary to carry off water, after it has done its duty.

a. Irrigation works.

Both the Barrage and the main canals, would in their present state, carry the discharges shewn in the early part of this report as necessary to provide ample sefi supply for the area at present requiring irrigation. It is only the July supply, required for the preparation of dura lands, which is beyond the carrying capacity of canals. However those branches which conduct water into the Bararis would have to be enlarged and extended.

It seems hardly worth while discussing the means of disposing of the July supply for only the existing cultivated area. It would scarcely pay to provide even one new Barrage, or to enlarge any one of the main canals, merely to permit of the present area of dura crop being planted early in July.

Under these circumstances no estimate will be made of the cost of new works and modification to old ones, with the object of disposing of what extra water would be provided, for an area limited to that at present cultivated.

I therefore pass on at once to a study of what would be necessary to dispose of the volumes of water. necessary to provide for the irrigation of the expanded area.

The first and most important question to be considered is how water is to be taken from the river, that is to say, how it is to be got into the canals.

There are four ways :

1. By strengthening the Barrage so that it might hold up water to a greater height than at present, in order, that by the canals flowing deeper, the increased discharge would be carried off.

2. By enlarging canals so as to carry off the increased supply without increasing the depth of water above the Barrage.

3. By constructing new Barrages at convenient points in the two branches of the river, leaving the old Barrage and main canals taking out above it unaltered.

4. By a combination of two, or more, of the foregoing alternatives.

Each alternative will be examined in turn.

1. To render the present Barrage sufficiently strong to hold up the required height so that existing canals would carry off the extra volume to be supplied, it would be undoubtedly necessary to construct another weir downstream, which, by holding up a certain depth of water, would reduce the pressure on the old work.

This arrangement would probably cost as much as entirely new Barrages further down the two branches, and since it is much better not to meddle with the old work, I think this alternative should be rejected.

The old Barrage does good work, therefore let well alone.

2. To enlarge canals sufficiently to carry off the increased supply at the present maximum height (R.L. 14) to which the old Barrage can hold up water, would entail, not only an enormous expenditure in earth and masonry works, but would involve the occupation of large areas of the most valuable land of the Delta. The latter reason alone condemns this alternative, however, for reasons given further on it cannot be altogether rejected.

3. New Barrages. This alternative is undoubtedly the most satisfactory. It is a great advantage to have the source of supply near the land for which water is required.

Although no water is allowed to pass the old Barrage in bad years like 1892, a considerable quantity nevertheless is found to be flowing down the branches of the river at Kafr Zayat and Mit Ghamr. This water comes of leakage from the sides of the river, and it is known, that at the places above mentioned, the daily quantity must have been 3 to 4 millions in 1892. New Barrages would allow of this water being used for irrigation. Four millions m³ per day will save 100,000 feddans of rice at the most critical time.

The area of land which would have to be taken up for channels to put the new Barrages in connection with existing canals would be trifling.

The cost of a Barrage in the Rosetta branch however would be very great, owing to its great length and depth of river bed below normal water surface. This is not the case with a Barrage in the Damietta branch, where the difference in level between the bed of the river and the adjoining ground, is much less than in the Rosetta branch.

It is difficult, indeed impossible, to give a definite verdict for, or against, a Barrage in the Rosetta branch without a more extended and closer study than I have as yet made.

There are so many points in favour of a Barrage, (especially gain in supply by intercepting infiltration which, otherwise, would flow out to the sea), that I will give alternative proposals, one providing for two Barrages, and the other a combination of Nos. 2 and 3 as described below.

4. The combination mentioned above is for (a) barrage in the Damietta branch in the neighbourhood of Mit Ghamr, which will ensure the water supply of nearly the whole of the Dakahlieh province and of the whole eastern halfof the Gharbieh province north of Samanoud; and (b) increasing the supply of the Bagurieh canal to insure the irrigation of the western half of Gharbieh, and the enlarging the Rayah Behera and its continuation, the Khatatbeh canal, for the irrigation of the Behera province.

Other barrages near the sea to keep out salt water would not be worth the money they would cost. It would be far more convenient to enlarge the sahil canals and turn all pumps, at present drawing from the Nile, on to them. I am of opinion it is better not to take them into consideration.

A few words are necessary to show what portion of the total increased discharge can be disposed of by the Barrage and existing main canals taking their supply from above it.

Together those canals would carry 35 millions m³ per day with the barrage at 14.00. Whereas the full June supply for the expanded area is 36 millions. Neither the Rayah Behera nor the Rayah Menoufieh are sufficiently large to carry the discharges allotted to them on page 9 whereas the 1st Circle's canals would carry more than the share allotted to that Circle.

Consequently effective use of these canals with the Barrage at R. L. 14.00 is equal to from 30 to 35 millions m³ a day. Whereas 36 millions in June and 72 in July have to be disposed of. It follows then that new provision has to be made for disposing of the maximum quantity, viz: 72—30= 42 millions.

Therefore, theoretically, from the month of May water would, of necessity, have to be passed forward. In practice, however, this would be the case all through the sefi season so as to maintain the pools above the new barrages at the required height.

I will now give in as few words as possible the works which will have to be constructed and those existing which will require modification, dealing with each alternative separately.

Two Barrages.

(*a*) DAMIETTA BRANCH.

The best position for the Barrage appears to be a short way north of Zifta and Mit Ghamr. It would hold up water to a height of from $3\,^1/_2$ to 4 metres, and supply the Buhiya, Um Sulima and Mansourieh canals and their branches, which together irrigate nearly the whole of the Dakahlieh Province on the eastern side of the river ; and by means of a short canal joining the river with the Sahil canal in Gharbieh, give that important artery a full supply.

The Bahr Shibin, below Rahbin, would be put in communication with the Barrage by a short channel from the Sahil canal near Samanud.

Thus Dakahlieh Province on the east, and the north eastern portion of Gharbieh on the west, would be supplied with water from the new Barrage. The canal above mentioned in Dakahlieh and the Sahil in Gharbieh would have to be enlarged and several new branches made, to provide water for the large expanse of reclaimable land in both these Provinces.

(*b*) ROSETTA BRANCH.

The position of a new Barrage in this branch is far more difficult to determine. If placed high up the branch, that is to say south of Kafr Zayat, it would have to raise the water surface upwards of 6 metres to be of any use for the Behera Province the level of which is very high as compared with the river bed. And even with this great head on the Barrage, water would have to be carried in long canals which would have to be dug parallel to the Khatatbeh canal in order to gain sufficient level.

If the Barrage is placed where a head of 3 to 4 metres would command the country a comparatively small area would be irrigated.

The neighbourhood of Quddaba, which is 145 kilometres north of the old Barrage and 23 kilometres north of Kafr Zayat, appears to be the most suitable spot, but even here the water surface would have to be raised 5 metres to give the same level as that now had in the canals on both sides of the river (1).

A very short channel on each side would put the Quddaba canal and the lower reaches of the Bagurieh in Gharbieh and the Khatatbeh in Behera in communication with the Nile.

The whole of the north western districts of Gharbieh and the Mahmudieh with its many branches in Behera would be supplied with water from this Barrage. Several canals, more especially the Quddaba and Sahil Markaz, would have to be enlarged and several new branches taking out of the first mentioned canal constructed to lead water to the extensive areas which, with irrigation and drainage, would be rendered fit for cultivation.

A lock would be necessary in each of the two barrages for river navigation (2).

So much for the scheme with two barrages.

The other alternative referred to above is for : —

One barrage in the Damietta Branch.

The barrage would, as in the first described case, be placed near Mit Ghamr, and the same canals in Dakahlieh supplied by it. But in Gharbieh a channel would connect up the Bahr Shibin at Santa, thus adding a larger area in the north east of this Province than that provided for in the other project.

There would be no barrage in the Rosetta branch, and the 2 to 3 millions per day of infiltration water would be lost for irrigation.

In order to provide for the north western districts of Gharbieh a larger supply would have to be passed down the Bagourieh.

(1) This head is too great, the site must be placed further down stream, see note further on.

(2) Since writing the foregoing, I have so far modified my ideas, as to consider that if a barrage is made anywhere in the Rosetta branch, it must be far down where the head may be limited to 4 metres. A lock will in this latter case be saved.

The Quddaba canal would still have to be enlarged and several new branches made as described for the alternative scheme with two Barrages.

The Behera Province would be entirely depended on the old Barrage, and water would have to be carried the whole length of the Rayah Behera and Khatatbeh canals, both of which would have to be enlarged as well as the Sahil Marqos. Enlarging and extending other canals will be the same as for the first alternative.

This ends the description of the second alternative. The rough estimated cost of the two will be given further on.

No mention has yet been made of the Sharkieh Province which has greater capabilities of expansion than the Dakahlieh Province. This Province however is quite independent of the proposed Mit Ghamr Barrage, and therefore the following details remains the same for both of the above mentioned alternatives. It derives its supply of water from the Ismailieh, Sharkawieh and Bahr Mues, which latter is a branch of the Rayah Tewfiki. All these canals take out of the Nile from above the old Barrage. By improving the Ismailieh and Sharkawieh, and their branches, and also those of the Bahr Mues, and by making new canals water will be carried to the large areas of reclaimable lands in the extreme north of the Province.

Both in the Gharbieh and Behera provinces several canals which derive their water supply from the old Barrage will require modification.

The most important are:

In Gharbieh. — At the tail of the Qasid canal are large expanses of reclaimable land; this canal and several of its branches would have to be enlarged and new branches made. This is referred to in estimate as central Gharbieh.

In Behera.—The Nubarieh would be enlarged and extended and new branches constructed to irrigate the reclaimable lands on the borders of Mareotis. This is referred to in the estimate as Behera south.

The two provinces of Qalioubieh and Menoufieh are at present cultivated to the full extent of their area. A better supply of water in the river could scarcely increase the area of sefi cultivation though it might ensure a plentiful supply of water used in irrigation.

b. Drainage works.

To describe the many works in connection with drainage would take too long.

It will suffice to say that in the four northern provinces of Sharkieh, Dakahlieh, Gharbieh and Behera, old drains will have to be enlarged and extended northward through reclaimable lands and southward into higher lands which, owing to more plentiful irrigation will need better drainage. Some new main drains and many new branches will have to be constructed.

The Mex pumps near Alexandria which under present circumstances merely limit the rise of Lake Mareotis will have to be increased in power, and large collecting drains carried through the middle of the lake.

Question. *The approximate cost of works?*

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3. — COST.

It is scarcely necessary to mention that the following is a very rough estimate of what the afore mentioned works will cost. To give accurate figures, extensive details, which are not forthcoming, would be necessary.

1. Irrigation works.

To provide for the disposal of whatever increase in the volume of water that may be had for existing cultivated area, omitting the large July supply, little is necessary which could not be done from ordinary annual allotments. The following estimate therefore refers only

to those works required to take advantage to the supply which it is calculated will permit of large extension in the cultivated area.

First alternative, viz : two new barrages.

The Damietta branch barrage will be about 400 metres long and will hold up a maximum of 4 metres, together with one lock and new head works for canals, may be put down as likely to cost	L. E.	400,000
The Rosetta branch barrages will be at least 600 metres long and will have to hold up 4 metres of water, together with one lock and head works, will probably cost not less than	»	700,000
Enlarging and improving canals in Dakahliyeh province	»	70,000
Gharbieh province, east	»	71,000
» » west	»	30,000
» » central	»	26,000
Behera province, north	»	33,000
» » south	»	40,000
Sharkieh province	»	70,000
Qalioubieh and Menoufieh	»	75,000
TOTAL	L. E.	1,515,000

Second alternative, viz: one barrage and enlarging certain main canals.

Damietta branch barrage as before	L. E.	400,000
Enlarging and improving canals in Dakahlieh province as before	»	70,000
Gharbieh province east	»	81.000
» » west	»	115,000
» » central	»	26,000
Behera province	»	400,000
Sharkieh province	»	70,000
Qalioubieh and Menoufieh	»	75,000
TOTAL	L. E.	1,237,000

The two alternative projects compare as follows: —

1. For two new Barrages one on each Branch L. E. 1,515,000.
2. For one new Barrage and enlarging certain canals L. E. 1,237,000.

The former has the advantage of utilising infiltration water of the Rosetta Branch which is upwards of 2 $^1/_2$ millions cubic metres per day which will irrigate 40,000 feddans of rice which may be valued at L.E. 100,000, and assuming that only once in five years this extra supply will be of any important use, that is to say, that four years out of five the ordinary supply would suffice for the area without the help of infiltration water, the annual benefit would be L. E. 20,000. This capitalized at 4 per cent amounts to L. E. 500,000 which is more than the extra cost of the first alternative project of two Barrages.

Drainage.

To complete the drainage of existing cultivated lands, the following is approximately the cost. These figures are based on estimates submitted by the Inspectors:

Eastern Provinces	L. E.	125,000
Gharbieh Province	»	85,000
Behera Province	»	60,000
TOTAL	L. E.	270,000

For the expanded area the above estimate must be increased by the cost of prolonging existing drains north and south, and for new drains.

The figures include the amounts given above :

Eastern Provinces	L. E.	200,000
Gharbieh Province	»	150,000
Behera Province	»	120,000
TOTAL	L. E.	470 000

The amount allotted to Behera includes the cost of enlarging the Mex Pumps.

L. E. 200,000 will therefore be necessary to provide for the drainage of new reclaimable lands.

The following is an abstract of the cost of the different estimates detailed above.

A. — Cost of providing ample irrigation and drainage for existing cultivated area.

I. Irrigation works. This as stated above is not estimated since most of what is necessary could be done from ordinary allotments.

II. Drainage, L. E. 270,000.

B. — Cost of providing ample irrigation and drainage for reclaimable lands in addition to existing cultivated area.

1. Alternative, viz: two Barrages.

I. Irrigation works	L. E.	1,515,000
II. Drainage works	»	470,000
TOTAL	L. E.	1,985,000

2. Alternative, viz: one Barrage and enlarging certain canals.

I. Irrigation works	L. E.	1,237,000
II. Drainage works	»	470,000
TOTAL	L. E.	1,707,000

Ghiseh Province.

These notes thus far have had reference only to the Delta Provinces, that is to say, to the Provinces situated north of Cairo.

Major Brown, Inspector General of Upper Egypt, has reported on Upper and Middle Egypt Provinces, that is to say, as far north as the northern boundary of Beni Suef. Between the last mentioned Province and the Delta lies the Province of Ghiseh which forms part of Middle Egypt though it is for convenience attached to the Inspector Generalship of Lower Egypt.

This Province, like those in Upper Egypt, is irrigated only once a year during the flood season. It is not as well of as Middle Egypt which has a summer supply from the Ibrahimiyeh Canal. There is however a certain area, on which summer crops are grown, irrigation being done by steam pumps erected on the river bank, and from wells of which there are numbers opposite Cairo.

The Province contains 188,000 feddans of which 36,000 are situated on the east of the river.

A long stretch of desert hills at the foot of which the Nile flows cuts off Eastern Ghiseh from the cultivated lands of Beni Suef. These 36,000 feddans cannot therefore be connected with any of the systems of canals coming from the south.

Of the remaining 152,000 feddans, all of which are on the west of the river stretching from the boundaries of Beni Suef to those of Behera at Khatatbeh which is more than 40 kilometres north of the Barrage, the most northern 10,000 have been included in the notes on the Delta. These 10,000 feddans will be irrigated from the Rayah Behera which is a Delta canal.

There is practically no room for expansion in Ghiseh. It is possible the desert valley between the Rayah Behera and the desert hills may in course of years become fit for cultivation. This area, however, is included in the 10,000 feddans above mentioned as forming part of the Delta.

As the existence of the Rayah Behera depends on this valley being flooded every year (when once rendered fit for cultivation flooding will no longer be necessary), canals must be so designed as to carry sufficient water for this purpose.

There are therefore 36,000 feddans on the east and 142,000 on the west to be considered.

Quantity of water necessary.

The whole Province will be capable of growing dry crops, such as cotton and sugar cane, in the summer. Assuming a three-yearly rotation, only $^1/_3$ the area will be under crop at the same time; 8 m³ per feddan per day over the whole area will doubtles be sufficient.

The total area of 178,000 feddans will therefore require 1,424,000 m³ per day, 288,000 m³ for the east and 1,136,000 m³ for the west.

2. Works necessary.

These will be, as in the Delta, of two kinds: irrigation and drainage.

Irrigation works.

On the east.

The surface of water in the river in summer falls so low as compared with the land that artificial means are necessary to raise it.

A barrage for so small an area is out of the question and, as mentioned above, a canal cannot be made connecting this area with the eastern districts of Beni-Suef.

The only means left therefore are steam pumps. These would be erected at the extreme south. A canal exists extending the whole length of the Province. Branches also exist; these with slight modifications would be suitable.

On the west.

Major Brown brings down the Middle Egypt canals system to the borders of Beni-Suef.

The same system will be carried on into Ghiseh. The existing Ghiseh canal would be utilized as the main artery, but it would require enlarging and extending southward to the boundary of Beni-Suef and northward to meet the Zumur canal, which latter canal would have to be improved.

Branches would distribute water on both sides.

Drainage works.

On the east.

Very little in this direction would be necessary. The width of cultivated land is so small and the Nile so deep, that there would always be good subsoil drainage. Nevertheless drainage would be necessary on the eastern side of the central canal.

On the west.

What is now the basin canal might be found suitable for a drain. This canal extends the whole length of the Province. It would doubtless have to be deepened and some branches constructed. Syphons to pass it under branch canals will also be necessary. Or it may be found better to dig an entirely new drain along the western extremity of valley close to the desert hills where the level of the ground is in general lowest.

3. Cost of works.

IRRIGATION.

On the east. — Pumps suitable for the high lift will probably cost.........	L.E.	35,000
Canals..	»	10,000
	L.E.	35,000
On the west. — Canals and Branches..................................	»	70,000
TOTAL..........	L.E.	115,000

DRAINAGE.

On the east.......	L.E.	10,000
On the west..	»	50,000
TOTAL..........	L.E.	60,000

ABSTRACT.

Irrigation works..	L.E.	115,000
Drainage works	»	50,000
TOTAL..........	L.E.	165,000

GENERAL ABSTRACT OF COST FOR THE LOWER EGYPT INSPECTOR GENERALSHIP.

The Delta	L.E.	1,707,000
Ghiseh..	»	165,000
TOTAL..........	L.E.	1,872,000

Question. — *The increased revenue to the country obtainable by such increase of supply.*

Indirect as regards the lands at present cultivated, which would be increased in value owing to the assured water supply.

Also indirect as regards land at present under flood irrigation only, which would be brought under summer irrigation.

Direct as regards lands at present waste and uncultivated owing to deficient water supply, which would be rendered culturable and yield a direct return to the State, both from the price derived from its sale and from the yearly tax above to be obtained from it.

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4. — FINANCIAL RESULTS.

The points to be considered are as follows : —

(a) Increase in the outturn of the crop on existing cultivated lands and consequent increase in value of the land itself.

(b) Increase in production of lands at present under flood irrigation and therefore giving only one crop per annum by the supply of summer water permitting of the cultivation of summer as well as flood crops, and the increase of the value of the land itself.

(c) Direct increase in revenue to the State by taxation of waste lands which would be rendered capable of cultivation by providing water for irrigation. Also the revenue derived by the sale of these lands.

It will be more convenient to separate Ghiseh, which really forms part of Middle Egypt from the Delta. I will therefore deal with each separately.

Ghiseh Province.

The whole of this province is at present nominally under basin irrigation producing a single crop. In reality, however, cotton is cultivated in « hoshas » or protected patches of land, and the area grown is annually increasing. It is inadvisable to calculate on any increase in direct taxation of land. The direct benefit to the proprietor will however be considerable.

It is not over estimating to take the summer crop as worth an average of L.E. 10 per feddan. 60,000 feddans will be under crop the value of which will be L.E. 600,000.

From this must be deducted the value summer crops cultivated under existing conditions, say 5,000 feddans and assuming the same value per feddan, viz: L.E. 10, we have L.E. 50,000.

This leaves a net profit of L.E. 550,000.

In addition to this the area planted with durah will largely increase and the outturn will be greater than at present.

This increase will amount to upwards of L.E. 150,000.

An extra cutting will be had from Bersim, but against this benefit, there is a decrease in area and quality of winter crops.

The total benefit accrueing to the province will therefore be L.E. 700,000.

The Delta.

There are many localities in high sweet lands where the summer supply is very precarious, indeed in some summer crops are unknown. These, with the reservoirs, will produce their share of cotton. Probably the total area does not exceed 30.000 feddans; nevertheless taxes are paid on them as for other land more fortunately situated in respect to summer supply. Assuming one third as growing cotton which produces 5 to 7 kantars and sells at L.E. 2 ½ per kantar, the crop will be worth L.E. 130,000.

The lower zone, viz: that between the old sweet and rice lands will benefit largely. Cotton often suffers at the northern extremity of this zone. The value of the increased area of crop may roughly be taken at L.E. 250,000.

Furthermore what is now simply rice growing land will more rapidly, with a more certain supply of water than at present, be sweetened sufficiently to produce cotton.

On pages 5 and 6 I calculated that dry crop growing area will increase from 2,650,000 to 3,040,000 feddans, the difference being 390,000 feddans.

Assuming that one half will be annually put under sefi which may be taken at L.E. 5 per feddan, the value of the outturn will be L.E. 975 000.

Next, there is the value of rice which will be grown on the 300,000 feddans of rice lands mentioned on page 6. Deducting from this the 160,000 feddans taken as producing rice at the present time, we have a net increase of 140,000 feddans.

Assuming two thirds as under crop every year and valuing it at L.E. 5 per feddan the total increase will be L.E. 500,000.

The insurance to the 160,000 by a certain supply may be estimated at L.E. 1 per feddan or L.E. 160,000 on the whole area.

The total increase in value of rice crop will therefore be L.E. 660,000.

The area of winter crops will also be greater. What are now rice lands will in course of time produce cereals and Bersim.

It will not be overestimating to assume an increase of 265,000 feddans of crops valued at L.E. 3 per feddan; this gives a total value of L.E. 795,000.

Lastly there is the dura crop. The extent to which the area at present cultivated will benefit is difficult to estimate.

The 900.000 feddans mentioned on page 8 may safely be assumed to bring in an increased outturn valued at P.E. 20 per feddan; the total extra value being L.E. 180,000.

The 100,000 feddans of new dura (page 7) would account for L. E. 300,000.
Thus the increase in the value of dura may be estimated at L.E. 480,000.

The foregoing figures give the gross additional wealth to the Delta as follows :

Cotton on high lands	L.E.	130,000
Cotton on the lower zone	»	250,000
Sefi on lands not at present producing this crop	»	975,000
Rice	»	660,000
Winter crops	»	795,000
Dura	»	480,000
TOTAL....	L.E.	3,290,000

or say in round figures 3 ¼ millions pounds per annum.

Government will benefit by an increase in direct taxation.

The whole 530,000 feddans of reclaimable land (page 5) will in course of time pay land tax. P.E. 50 per feddan is probably not too high a figure. This gives a revenue of L.E. 265,000 per annum.

There are also lands which, as before stated, will, with a more certain water supply, produce more valuable crops. The tax on these will increase in proportion to the benefit accrueing to them by better water supply. This may be assumed at L.E. 35,000.

The total increase in direct revenue from land may be taken at L.E. 300,000 per annum.

Of the reclaimable area of 530,000 feddans (page 5), a certain portion is already private property; the greater portion however belongs to the State.

Some of these lands will produce fair crops as soon as irrigation and drainage are provided and they should bring in cash. Others are very salt and will require a considerable outlay before they will be fit for cultivation. I do not think it will be wise to calculate on more than L.E. 200,000 for the sale of these lands.

THE WADY RAYAN AS AN ESCAPE.

A height of 24 pics on the Roda gauge at Cairo would be a very convenient maximum to fix for the flood rise. The Delta would be preserved from the worst forms of infiltration, and in consequence a much smaller destruction of crop; guarding banks would be rendered far more easy and less costly.

Assuming the floods of 1874 & 1878 as those which produced the maximum rise at Cairo, the Wady Rayan Canal would have to discharge, 185 millions cubic metres per day in order to insure the rise at Cairo never exceeding 24 pics.

A discharge of 100 millions cubic metres per day taken out of the river would limit the maximum rise to about 24 pics 10 kirats which would however be a dangerously high level.

EDWARD W. P. FOSTER,
Inspector General, Lower Egypt.

Cairo, 29th November, 1893.

APPENDIX XIII.

TRANSLATION OF

A NOTE

BY

D^{R} SCHWEINFURTH

ON THE SALT IN THE WADY RAYAN.

Cairo, 15th December, 1893.

SIR,

You have reminded me of the conversation we had last May on the subject of the proposed /ady Rayan reservoir, and of the possibility of its becoming brackish. I now have the onour to present you with my report on this important question. The report of necessity als only with rough approximations.

I have, etc., etc., etc.

G. SCHWEINFURTH.

To

W. E. GARSTIN,

Under Secretary of State,

Public Works Department, Cairo.

REPORT

ON THE SALT(1) IN THE WADY RAYAN RESERVOIR

BY G. SCHWEINFURTH.

An exact valuation of the amount of salt which will be contained in this reservoir, when the water has risen to a height of 27 metres above the Mediterranean, cannot be made, owing to the absence of information on some of the following points: —

Data wanting.

1. The percentage of salt in the soil of the Reservoir bed.
2. The thickness of the salty strata of the bed permeable to water.
3. Mean specific gravity of the desert soil of the reservoir and the feeder canal.
4. The time of filling.
5. The dimensions of the canal and the area of the lands flooded by the canal.
6. The percentage of salt in the desert soil traversed by the canal, and the extent of the inundation.
7. The thickness of the strata permeable to water in the bed and sides of the canal.
8. The percentage of salt in the Nile deposits traversed by the canal in the Nile valley.
9. The thickness of the strata permeable to water in this last canal.
10. The mean specific gravity of the Nile deposits traversed by the canal.
11. The volume of subsoil water which will enter the canal by infiltration and the percentage of salt in it.

To find an approximate value we can however substitute for the exact data, approximate ones, based on observed facts and obtained tentatively.

Numbers 4 and 5 are of the greatest importance in your present inquiry. I shall show further on that if the filling lasts 7 years, it will in no way compromise either the Nile or the cultivation, but if the filling is slow the water of the reservoir will be unfit for irrigation.

Agricultural axioms.

Once salt is contained in the water of the reservoir, there it will remain for ever unless there is outflow. This is a fundamental truth in Egyptian agriculture, which is nothing but a continued fight against salt. If there is no outflow, the constant entry of Nile water can in no way remedy this state of affairs, and the salt will accumulate owing to evaporation all the years that the reservoir is being filled.

Salt is unalterable.

Salt (chlorure of sodium) undergoes no chemical transformation in contact with Nile water, or with any of the substances the water contains in suspension or solution. One other peculiarity of the salt is the invariableness of its degree of solubility under different temperatures.

Earth and rock specimens should be analysed.

To obtain the percentage and specific gravity of the salts contained in the desert soils in the reservoir a special inquiry should be instituted.

A large and varied number of specimens should be analysed chemically to find the mean quantity of the salt.

(1) By "salt" I always mean "Chlorure of Sodium".

The surface of the Wady Rayan, as compared to other parts of the desert, contains a large quantity of salt because the rain fall finds no escape from the depression, and concentrates there the salt of the adjacent lands. The efflorescence also, which is always more active where the ground is alternatively wet and dry, tends to augment the quantity of salt at the bottoms of depressions which have no outlet. During my visit in 1884 I myself saw quantities of salt at the surface of the ground in the Wady Rayan. There is a single spring of sweet water, but it becomes brackish after flowing a short distance and gives birth to scarcely any vegetation.

Limits of cultivation in salted lands.

In Egypt it has been found by observation that certain wild and cultivated plants can support 2 per cent of salt in the soil, provided that the latter is perpetually humid. Under these conditions of perpetual humidity the salt may rise to 4 per cent before rendering the soil absolutely sterile. On the contrary a soil which is alternately wet and dry is rendered sterile by one per cent of salt.

Almost all the desert soils of the tertiary formation in the interior of Egypt are naturally uncultivable without washing and draining. It is for the same reason that they are generally devoid of wild plants.

Natural drainage in the desert.

The *high limestone plateaus* of the eastern desert above 1,000 metres in height, the Mediterranean *littoral*, and the *beds* of all torrents are an exception. These lands have lost the salt which is contained in all limestone strata in clay strata, and on the desert plains. The more abundant winter rains in the two first instances, and in the case of the third, the concentrated drainage of the rare falls of rain, have produced this result.

The maximum percentage of salt possible in the desert soils.

In accordance with these facts, one may roughly estimate, without fear of exaggeration, the maximum quantity salt in the desert soil as 2 per cent. I shall use this figure in my calculations and I am confident it will never be surpassed by the result of the analysis proposed by me.

The thickness of the stratum accessible to the dissolving action of the water may be taken as 20 centimetres at the bottom of the Wady Rayan; and as 50 centimetres for the bed and sides of the canal, and the inundated lands which will be more thoroughly washed and undermined by the waves.

Categories of desert soils.

One can distinguish 3 categories of desert soils of tertiary origin as far as their permeability is concerned; and also as to the ease with which the salt they contain can be dissolved.

(1) Solid rocks; beds of limestone, of silicious and argillacious limestone, and of calcarious sandstone.

(2) Loose soils, composed of decomposed rocks, pebbles, boulders, shingle, etc.

(3) Marly clays and sands, in layers overlying the plains, in the undulating slopes of the hills, and at the feet of bluffs.

To arrive methodically at the mean percentage of salt, it becomes necessary to make a quantitative chemical analysis of each of the three categories of soil separately, then measure their specific gravity, discover the thickness of the stratum which is permeable, and finally fix on the area. These are the necessary elements. The calculation which follows has no pretence to such precision.

[illegible]

The following are the established or approximate facts which are at my disposal: —

1) Dimensions of the canal traversing the desert:

Length	25 kilometres
Breadth	40 metres.
Depth of water	9 metres.

(2) Time of filling probably 7 years.

(3) Volume of water contained in the reservoir below R. L. + 27^m = 18,600 millions of cubic metres.

(4) Superficies of the water at R. L. 27... 650 millions of square metres.
(5) Annnal evaporation... 2 metres.
(6) Salt contained in Nile water after Professor Sickenberger's analysis in 1883, 40 milligrammes per litre = 40 grammes per metre cube $= \frac{1}{250}$ per cent.
(The Nile in summer has only $\frac{1}{2000}$ per cent of salt).
(7) The mean specific gravity of salt 2.25.
(8) Solubility of salt water 1 : 2.75.
(9) The specific gravity of the mean desert soils has been taken as practically the same as that of salt.

Estimate of salt in the Wady Rayan reservoir.

The different sources from which salt can enter the proposed reservoir are enumerated in the following list: —

	SALT IN THE RESERVOIR IN MILLIONS OF GRAMMES
1. From the Nile in flood when the reservoir is full : 18,600 millions $\times$ 40 =	744,000
2. From the Nile in flood, to make good the losses from evaporation in 7 years : 3,000 millions of cubic metres $\times$ 40.......................... =	120.000
3. The losses by evaporation in the canals during 7 years .... =	36,000
4. From the lands in the bed of the reservoir : 650 millions square metres $\times$ by $0^m.2$ = 130 millions cubic metres (130,000,000 $\times$ 2.25) = 290 billions of grammes, of which 2 per cent amount to............... ...... =	5,800,000
5. From the bed and banks of the canal in the desert and the inundations : 2 per cent of salt in a belt of 50 centimetres........................... =	650.000
6. From the Nile deposits composing the bed and banks of the canal in the Nile valley 20 kilometres long.	
7. From infiltrations and drainage into the same canal.................. =	150,000
TOTAL........	7,500,000

This equals 7,500,000 millions of grammes or, 0.04 per cent.

The reservoir would therefore contain 7,500 millions of kilogrammes of salt, or $\frac{1}{25}$ per cent of salt; that is to say $\frac{1}{2}$ of the salt which exists in the water of those wells in Egypt which can be used for purposes of irrigation.

Substitution of exact for approximation data.

Water containing a similar proportion of salt could be turned into the Nile without in any way compromising the agriculture. I again report that my calculation is based on maximum and assumed data. To obtain an exact calculation we must obtain exact data.

The phenomenon of sweet water in the Qurun lake.

I conclude by calling attention to the extraordinary phenomenon of the water of Lake Qurun in the Fayum being nearly sweet, in spite of the fact that it is the residuum of the ancient Lake Mœris. This question is intimately connected with that of the Wady Rayan reservoir. Very probably the creation of the depression of the Fayum and the subsidence of the strata composing its bed were due to the same geological action which produced the Wady Rayan. This reflexion makes it probable that this latter reservoir, when it is full, will disclose the same clefts and fissures in its bottom, which I shall try and prove, exist in the bed of the Qurun lake.

The great probability of subterranean drainage from the Wady Rayan.

These subterranean passages will cause the loss of a great part of the water stored in the reservoir, and will give birth to distant springs, and probably even to the formation of new oases in the Libyan desert. The effect on the reservoir will be the following : the quantity of salt in the reservoir will be diminished, but the work of the filling the reservoir will be more difficult and longer in operation.

(1) According to Sickenberger ordinary well water in Egypt, which is used for irrigation, contains $^1/_{12}$ per cent of salt.

The Qurun lake has to-day a surface of about 250 millions of square metres and probably a cubic content of 1500 millions of cubic metres.

If we suppose that the lake has existed at this same level since the Roman period (A. D. 200), the lake would have received salt from the Nile since that period.

The salt contained in the Fayûm lake.

	IN MILLIONS OF GRAMMES
(1) Salt in the entire mass of the water, 1500 × 40 .... =	60,000
(2) Salt contained in the strata of water evaporated annually during 17 centuries, 2 × 250 × 40 × 1700 .... =	34,000,000
TOTAL....	34,060,000

The salt in this case would amount to 34,060 millions of kilogrammes i. e. 2.27 per cent.

As however, at the time in question, the lake had very probably its water level at + 0, its volume are decreased by 43 metres in perpendicular height during the 17 centuries. We must therefore find the quantity of salt in the water which was in excess of the present volume of the lake, and the annual loss by evaporation off the excess of the surface of the lake over the area of to-day. This latter excess equalled, in all probability, the present area of the lake.

At R. L. 0 the area of the lake was approximately 500 millions of square metres, and its excess volume was from 13 to 14 times the actual volume of to-day. I estimate this excess volume at 20,000 millions of cubic metres and the salt at 800,000 millions of grammes. The diminution of the surface of the lake was slightly under 250,000 square metres per annum. The salt contained in the strata of water evaporated outside of the actual area of the lake today amounted in 17 centuries to 17 billions of grammes. This total quantity of 17,800,000 millions of grammes of salt in 1500 millions of cubic metres of water give a percentage of 1.186.

If we add 1.186 to 2.27 found before, we have 3.45 per cent of salt in the lake to-day if it had existed only 1,700 years ; and at the beginning of that time, had been at level of the Mediterranean.

Other sources of salt in the lake hitherto omitted.

So far I have not considered the supply of salt from other sources such as : —

(1) The infiltration water brought into the lake by the canal and drains from the cultivated land of the Fayûm.

(2) The greater quantity of salt in the Bahr Yusif on the entering the Fayûm, than in the Nile itself.

On the other hand I have exaggerated in giving for the whole year the percentage of salt which is in the Nile only during flood.

Any way, one will readily see to what degree of concentration the salt ought to increase in a lake whose volume has been so considerably reduced through incalculable centuries. The vestige of the ancient water surface which are to be found to the north of the lake at a distance of 8 kilometres from its present edge near the temple discovered by me in 1884, and the other incontroventible proofs of the existence of a Mœris in the sense of Herodotus, make it very probable that its level rose in ancient times to a level of 22 or 23 metres above the Mediterranean.

The quantity of salt derived from Mœris.

According to Major Brown, the ancient Mœris had a surface of 1,600 millions (1) of square metres. Its volume may be calculated at 30,000 millions of cubic metres. This volume, reduced to 1,500 millions cubic metres, brings the percentage of salt in the water of the actual lake to .8 per cent by itself, and the salt contained in the stratum evaporated during a single year being 120,000 millions of grammes, ought in 10 centuries, to mount to 128,000 miltions of kilogrammes. This would represent in the 1,500 millions of cubic metres, of the lake of to-day, a percentage of 8,53.

(1) On page 26 of the Report, the area of the ancient lake Mœris is given as 2,500 square kilometres.

But who knows since when the great lake existed, and how many centuries elapsed before the controlling of its water was begun? What has become of the salt which would have mounted to figures far higher than mine? Where again are the salts contained in the basin before the Nile water entered, and the salt of infiltration from drainage and irrigation? The salt in the lake to-day bears no relation to the quantities I have enumerated. **8.5 per cent of salt at least has disappeared in the Fayûm lake.**

To-day the waters of the Qurun lake are but slightly brackish. They are even potable, and inhabited by fresh water fish from the Nile. It has been definitely proved that lake Mœris never had a natural outlet towards the interior of the country, and that it never even was in connection with the Wady Rayan which it nearly touched. (See Major Brown's work on the Fayûm p. 43 and 48). The Fayûm basin is closed on all sides by bluffs and hills of considerable height. We have seen that, in spite of their concentration through immemorial ages, the salt in the waters of the lake has not increased. This renewal of fresh water can only be accounted for by subterranean drainage. Where have the waters gone to?

(Lake Tchad in the central Soudan is an example of subterranean drainage on a larger scale. The waters are perfectly sweet in spite of the absence of any apparent outlet. The lake is drained by active infiltrations towards the N. E. in low depressions which are known as the Bahr El Gazal).

The Natron lakes are probably due to direct infiltrations from the Nile, since Sickenberger in 1892 observed that all the springs which gave birth to the lakes were situated on the eastern side of the valley. The difference of level, also, prevents the establishment of any similarity between the systems, as well as the fact that the springs of the Natron lakes are not thermal.

Oases and depressions provided with springs are to be found to the north west of the Fayûm as far as Siwah; and this latter oasis may perhaps obtain some of its water from the Qurun lake in spite of the difference of levels. There are many phenomena connected with thermal springs which as yet await solution. We are still in ignorance of the destination of the currents of those thermal springs which traverse the bottom of the depression of the great oasis and the oasis of Dakhel, at great depths. These springs are abundant and flow evidently towards the north. It is probable that all these subterranean streams, which are fed by the Nile, flow towards the Marmarica coast between Alexandria and Derna. There, owing to the tensile force inherent in all water at a high temperature, they are discharged at great depths below the level of the Mediterranean sea.

Signed: G. SCHWEINFURTH.

[redacted]